CHARACTERISATION AND DESALINATION OF TYPICAL SOUTH AFRICAN ABALONE FARM EFFLUENT SEA WATER

by

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DECLARATION

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ABSTRACT

Nearly all South African abalone farms function on an intensive pump-ashore, flow-through system. Large volumes of sea water that are pumped ashore flow through abalone or kelp harvesting tanks and finally gravitate back to the ocean. If the effluent from an abalone farm can be desalinated without permanent membrane fouling, then sea water reverse osmosis (SWRO) technology can be integrated effectively with established abalone farms without having to increase the farms' intake system capacities. Without the need to construct and maintain an intake system, the overall cost of desalination can be reduced. Therefore, the aim of this study was to determine the feasibility and viability of integrating a SWRO desalination plant with a typical South African abalone farm. The project focused on four areas of concern, namely:

- characterisation of typical South African abalone farm water
- SWRO desalination plant pilot study and membrane fouling behaviour
- general operation of a typical abalone farm and its implications for desalination
- cost estimates and implications for the integration of an SWRO desalination plant with an abalone farm

During a nine-month on-site investigation, sea water turbidity was reduced by up to 43% from a mean value of 0.82 NTU in the influent stream to 0.47 NTU in the combined effluent stream from the abalone tanks. Even with spikes in the influent turbidity, the turbidity of the combined effluent from all abalone tanks (excluding tank flush water) remained below 1 NTU. Dissolved organic carbon (DOC) in both the influent and combined effluent remained below 1 mg/litre.

Ultrafiltration (UF) was selected as pre-treatment to the reverse osmosis (RO) in order to minimise potential fouling of the RO membranes. Membrane compaction of both the UF and RO membranes contributed significantly to initial flux losses – as much as 18% for the polyethersulfone (PESM) UF membranes and 20% for the thin film composite (TFC) polyamide RO membrane. However, this is comfortably in line with typical compaction values quoted in the literature.

Without pre-flocculation, the UF was able to operate at a specific flux between 45 and 55 litre/m^2/h (LMH) and recoveries ranging between 60 and 75%. Corresponding trans-membrane pressure (TMP) ranged between 0.59 and 0.76 bar. With ferric chloride pre-flocculation at a concentration of 3 mg/litre (as Fe^{3+}) the UF could be operated at notably lower TMP values between 0.11 and 0.36 bar. These results indicate that provision should definitely be made for pre-flocculation when using UF as pre-treatment, despite the fact that the DOC concentrations and turbidity of the abalone farm effluent are quite low (DOC <1 mg/litre, NTU <1). It furthermore highlights the inability of DOC and turbidity alone to predict the membrane fouling potential of water.

A better indicator of membrane fouling potential, albeit not perfect, is the modified fouling index ($MFI_{0.45}$). This index follows a linear trend with foulant concentration and serves as a good indicator of the filterability of water. On-site measurements showed an *increase* in mean $MFI_{0.45}$ values from 29 s/litre^2 for the influent to 48 s/litre^2 for the effluent from the abalone tanks, thereby confirming the need for pre-flocculation as part of UF pre-treatment.

Chemically enhanced backwashing (CEB) of the UF membrane at least every 24 hours was found to be essential for its stable operation. Therefore, UF with pre-flocculation (3 mg/litre Fe^{3+}) and regular CEB can be used effectively as pre-treatment method for the desalination of abalone farm effluent water.

An RO 'feed-and-bleed' system was used to simulate the typical performance of the last membrane in a full-scale RO membrane bank. This RO membrane performed well with no signs of extreme fouling. The membrane produced a good quality permeate – for the last membrane in a membrane bank – reducing the TDS of the RO feed from 33 493 mg/litre to 969 mg/litre. These results compared well with simulated values by *Reverse Osmosis System Analysis* (ROSA; an RO simulator by DOW), indicating a TDS reduction from 33 271 mg/litre to 1 409 mg/litre at a feed pressure of 56 bar, and overall recovery of 44%.

A steady performance of the RO membrane during the pilot study indicated that it is possible to desalinate abalone effluent water without notable permanent membrane fouling. A stable normalised flux rate of 8 LMH was achieved and RO membrane integrity remained intact with a salt rejection that ranged from 98.0 to 98.5%. No sudden reduction in permeate flux was observed as a result of fouling by unknown constituents present in the UF permeate. DBNPA (a non-oxidising disinfectant) was dosed once per week at a concentration of 10 – 30 mg/litre for 30 minutes. Scaling was controlled effectively by means of an antiscalant dosed at a concentration of 11 – 12 mg/litre in the feed stream. The CIP frequency was not optimised but a CIP frequency of once every 6 – 8 weeks appeared to be more than adequate to prevent permanent membrane fouling

Advantages of integrating an SWRO desalination plant with a South African abalone farm include:

- no lengthy and costly environmental impact assessment (EIA) is required to build a new intake system
- shared capital and operational cost of intake system
- dual incentive to keep constant good quality water flowing through the farm
- early warnings regarding occurrences such as algal bloom and red bait
- shared operational and management cost to keep pipelines clean
- electricity saved (pumps for intake system)

Disadvantages of integrating an SWRO desalination plant with a South African abalone farm include:

- will require diverting of the abalone tank wash water from regular effluent
- possible water 'down-times' due to maintenance operations on abalone farm

Based on information from the literature the fixed capital cost depreciation rate (FCCDR) typically contributes approximately 40% and the operation and maintenance (O&M) cost typically contributes 60% to the unit production cost (UPC) of desalinated water. Furthermore, a SWRO desalination plant's intake system can contribute between 5% and 33% to the FCCDR, depending on the nature and design of the plant. Consequently, the intake system can contribute between 2% and 13% of the UPC of desalinated sea water. This implies possible cost savings of between R0.15/m^3 and R2.37/m^3 for the production of fresh water (depending on site-specific design factors) when desalinating sea water effluent from on-shore abalone tanks.

Integration of an SWRO desalination plant with a South African abalone farm is feasible and viable, provided that the necessary steps and precautions are taken to ensure a smooth and stable operation of the SWRO desalination plant. Cost savings on the part of all the stakeholders are possible if the correct contract can be negotiated.

OPSOMMING

Byna alle Suid Afrikaanse perlemoenplase funksioneer op ‘n seewater deurvloeistelsel. Groot volumes seewater word aan wal gepomp en vloei deur die perlemoen of kelp-oes tenks. Hierdie water vloei dan uiteindelik terug na die oseaan as gevolg van swaartekrag. Indien die afvalwater van die perlemoenplase ontsout kan word sonder permanente membraanbevuiling kan seewater tru-osmose (SWTO)-tegnologie effektief met gevestigde perlemoenplase geïntegreer word sonder om die plase se water inname-stelsels se kapasiteite te vergroot. Sonder die behoefte aan uitbreiding en instandhouding van ‘n water inname-stelsel by so ‘n plaas behoort die totale koste van ontsouting aansienlik minder te wees. Die doel van hierdie studie was dus om die uitvoerbaarheid en lewensvatbaarheid van ‘n integrasie van ‘n SWTO ontsoutingsaanleg met ‘n tipiese Suid Afrikaanse perlemoenplaas te ondersoek. Ten einde dit te doen, het die projek op vier areas van belang gefokus, naamlik:

- karakterisering van tipiese Suid-Afrikaanse perlemoenplaas water
- SWTO ontsoutingsaanleg loodsstudie en membraan bevuilingsgedrag
- algemene bedryf van ‘n tipiese perlemoenplaas en die implikasies vir ontsouting
- kosteberamings en koste-implikasies met betrekking tot die integrasie van ‘n SWTO ontsoutingsaanleg met ‘n perlemoenplaas

Gedurende ‘n nege maande op-perseel ondersoek is seewater troebelheid verminder met tot 43% van 'n gemiddelde waarde van 0.82 NTU in die invloeistroom tot 0.47 NTU in die gekombineerde afvalwaterstroom wat die tenks verlaat. Selfs met skerp wisseling in die invloeistroom troebelheid, bly afvalwaterstroom troebelheid deurgaans onder 1 NTU met die uitsondering van tenk spoelwater. Opgeloste organiese koolstof (OOK) in beide die invloeistroom en die gekombineerde afvalwaterstroom het deurgaans onder 1 mg/liter gebly.

Ultrafiltrasie (UF) is gebruik as voorbehandeling vir die tru-osmose (TO) om sodoende potensiële bevuiling van TO membrane te minimaliseer. Membraan kompaksie van beide die UF en TO het merkbaar bygedra tot aanvanlike deurvloeiverliese – so veel as 18% vir die poli-etersulfoon (PESM) UF membrane en 20% vir die dun film saamgestelde (DFS) poli-amied TO membraan. Hierdie is egter gerieflik binne die tipiese kompaksiewaardes soos aangehaal in die literatuur.

Sonder flokkulasie was die UF in staat tot temperatuur aangepaste deurvloeitempo van tussen 45 en 55 liter/m^2/h (LMH) teen herwinningstempo’s tussen 60 en 75%. Ooreenstemmende trans-membraandrukkings (TMD) het gewissel tussen 0.59 en 0.76 bar. Met ysterchloried voor-flokkulasie teen 'n konsentrasie van 3 mg/liter (as Fe^{3+}) kon die UF teen merkbaar laer TMD waardes bedryf word – tussen 0.11 en 0.36 bar. Hierdie resultate dui daarop dat daar beslis voorsiening vir pre-flokkulasie gemaak moet word wanneer UF as voorbehandeling gebruik word, ten spyte van die feit dat die OOK konsentrasie en troebelheid van die afvalwater van die perlemoenplaas redelik laag is (OOK <1 mg / liter, troebelheid <1 NTU). Verder lig dit die onvermoë uit om OOK en troebelheid alleen te gebruik om membraanbevuilingspotensiaal van water te voorspel.

‘n Beter aanwyser van membraanbevuilingspotensiaal, alhoewel nie perfek nie, is die aangepaste bevuilingsindeks ($MFI_{0.45}$). Hierdie bevuilingsindeks volg ‘n lineêre neiging met die konsentrasie van onsuiwerhede en dien as ‘n goeie aanwyser van die filtreerbaarheid van water. Op-perseel metings het getoon dat ‘n toename in gemiddelde $MFI_{0.45}$ waardes van 29 s/litre^2 vir die invloeistroom tot 48 s/litre^2 vir die afvalstroom van die perlemoentenks die behoefte vir voor-flokkulasie as deel van UF voorbehandeling bevestig.

Chemies versterkte terugspoeling (CVT) van die UF membrane ten minste elke 24 uur is noodsaaklik gevind ten einde bestendige werking te verseker. Dus kan UF met voor-flokkulasie (3 mg/liter Fe^{3+}) en gereelde CVT effektief as voorbehandeling metode vir die ontsouting van perlemoenplaas afvalwater gebruik word.

'n TO 'voer-en-bloeistelsel' is gebruik om die tipiese prestasie van die laaste membraan in 'n volskaalse TO membraanbank te simuleer. Hierdie TO membraan het goed presteer sonder tekens van buitensporige membraanbevuiling. Vir die laaste membraan in 'n membraanbank het die membraan goeie gehalte finale water gelewer – 'n vermindering van die totaal opgeloste stowwe (TOS) van die TO voerwater van 33 493 mg/liter tot 969 mg/liter is behaal. Hierdie resultate het goed vergelyk met gesimuleerde waardes deur *Reverse Osmosis Analysis System* (ROSA, 'n TO simulator deur DOW) wat 'n TOS vermindering van 33 271 mg/liter tot 1 409 mg/liter by 'n voerdruk van 56 bar en 'n algehele herwinningstempo van 44% aandui.

'n Bestendige werking van die TO membraan tydens die loodsstudie het getoon dat dit moontlik is om perlemoenplaas afvalwater te ontsout sonder merkwaardige permanente membraanbevuiling.

'n Stabiele genormaliseerde deurvloeitempo van 8 LMH is bereik en TO membraan integriteit het ongeskonde gebly met 'n sout verwerping wat gewissel het van 98.0 tot 98.5%. Geen skielike afname in finale water deurvloeitempo is waargeneem as gevolg van bevuiling deur onbekende onsuiwerhede in die UF finale water nie.

DBNPA ('n nie-oksiderende ontsmettingsmiddel) is een keer per week teen 'n 'n konsentrasie van 10 – 30 mg / liter vir 30 minute gedoseer. Mineraal skaalvorming is effektief beheer deur die dosering van 'n anti-skaalmiddel teen 11 – 12 mg/liter in die TO voerstroom. Die skoonmaak-in-plek (SIP) frekwensie is nie ge-optimeer nie, maar 'n SIP een keer elke 6 – 8 weke is meer as voldoende gevind om mikrobiese bevuiling te voorkom.

Voordele van die integrasie van 'n SWTO ontsoutingsaanleg met 'n Suid-Afrikaanse perlemoenplaas sluit die volgende in:

- geen lang en duur omgewings impak ontleding (OIO) is nodig vir die bou van 'n nuwe inname-stelsel nie
- gedeelde kapitaal en operasionele koste van inname-stelsel
- tweeledige aansporing om konstant goeie gehalte watervloei deur die plaas te verseker
- vroegtydige waarskuwings ten opsigte van gebeurtenisse soos rooigety
- gedeelde bedryfs- en bestuurskoste om voerpype skoon te hou

Nadele van die integrasie van 'n SWTO ontsoutingsaanleg met 'n Suid-Afrikaanse perlemoenplaas sluit die volgende in:

- vereis herleiding van perlemoentenk spoelwater weg van gereelde afvalwater
- moontlike watervloei-aftye weens instandhoudingsbedrywighede op die perlemoenplaas

Gebaseer op inligting uit die literatuur dra die vaste kapitaal koste waardeverminderings-koers (VKKWK) gewoonlik ongeveer 40% en die bedryfs- en instandhoudingskoste (B&I) ongeveer 60% by tot die produksiekoste per eenheid (PKE) van ontsoute water.Verder kan 'n SWTO ontsoutingsaanleg se inname-stelsel tussen 5% en 33% tot die VKKWK bydra afhangende van die aard en ontwerp van die aanleg. Gevolglik kan die inname-stelsel tussen 2% en 13% tot die PKE van ontsoute seewater bydra. Dit impliseer 'n moontlike kostebesparing van tussen R0.15/m^3 en R2.37/m^3 vir die produksie van vars water wanneer die afvalwater van perlemoentenks ontsout word.

Integrasie van 'n SWTO ontsoutingsaanleg met 'n Suid-Afrikaanse perlemoenplaas is uitvoerbaar en lewensvatbaar indien die nodige stappe en voorsorgmaatreëls geneem is om ‘n vlot en bestendige werking van die SWTO ontsoutingsaanleg te verseker. Kostebesparings vir alle belanghebbendes (beleggers) is moontlik indien daar oor die korrekte kontrak onderhandel kan word.

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NOMENCLATURE

The following symbols are used frequently in the report and are of importance to the reader.

Symbol:	Description:	Units:
Alphabetic		
A	membrane surface area	m^2
C	concentration , conductivity	mg/litre ,µs/cm
CF	conditioning factor/concentration factor	dimensionless
dP	applied pressure	Pa
dP_0	reference applied pressure 2.07 X 10^5	Pa
$DISL$	daily increment in shell length	µm/day
G	velocity gradient for rapid mixing	s^{-1}
g	gravity constant	m/s^2
I	fouling potential index	m^{-2}
i	interest rate	%
J	flux	l/m^2h (lmh)
K	transport/permeability coefficient	dimensionless
m	molality	mol/kg
NDP	net driving pressure	Pa
P	dissipated power, pressure	W; Pa, bar
$\%P_{30}$	percent plugging at 207kPa (30 psi) feed pressure	%
pK_2	$-\log_{10}[\mathrm{K_2(mol/L)}]$ ($\mathrm{K_2}$ = ionization constant of $\mathrm{HCO_3}$)	mol/litre
pK_2	$-\log_{10}[\mathrm{K_S(mol/L)}]$ ($\mathrm{K_S}$ = solubility product of $\mathrm{CaCO_3}$)	mol/litre
$pAlk$	$-\log_{10}[\mathrm{Alk(mol/L)}]$ (Alk = total alkalinity)	mol/litre
pCa	$-\log_{10}[\mathrm{Ca^{2+}(mol/L)}]$	mol/litre
R	recovery	%

Symbol:	Description:	Units:
Greek Symbols		
Δ	*difference/change in property*	-
Σ	*summation*	-
Σmi	summation of molality of all ionic and non-ionic constituents in the seawater	
ΔH	head loss over mixing tank	m
$\Delta\pi$	trans membrane osmotic pressure	Pa/bar
μ	dynamic water viscosity	Pa.s, N·s/m^2
η	viscosity at water temperature	kg/(m.s)
π	osmotic pressure	Pa/bar
ρ	density	kg/m^3
τ	residence time in the mixing zone	s
φ	osmotic coefficient for seawater	dimensionless
Subscripts		
0	reference conditions	
a	actual	
b	brine	
c	concentrate	
f	feed	
i	initial, constituent i	
m	membrane	
p	permeate	
s	standard, salt	
T	temperature	
t	time	
wt	water transport	
o	operating conditions	

GLOSSARY

The following terms are used frequently in the report and are of importance to the reader.

Term:	Description:
Abalone Tank Effluent	Effluent seawater from the abalone tank which flows to the gulley of the abalone farm and then gravitationally flow back into the ocean.
Antiscalant	A chemical that inhibits scale formation.
Backwash	The process of reversing the flow of water either across or through a medium or membrane.
Coagulation	Coagulation is the process of adding chemical reagents in a mixing device to destabilise colloidal particles and allow them to agglomerate or flocculate with other suspended particles to form larger more readily settled particles.
Concentrate (RO), or Retentate (UF&MF)	The term used to describe the liquid that does not migrate through the membrane and which contains all of the retained salts and impurities.
Concentration factor	The factor by which the concentration of salt in the feed increases during desalination, i.e. the ratio of the salt concentration in the concentrate versus the salt concentration in the feed.
Concentration polarization coefficient	The ratio between the salt concentration of the salt directly adjacent to the membrane (in the boundary layer on the membrane surface), C_M , versus the salt concentration of the liquid to be treated, C_F.

Term:	Description:
Filtered Raw Seawater	Seawater that is passed through two sets of drum filters for use on an abalone farm; primary drum filters (60-1000 micron) and secondary drum filters (25-35 micron).
Flocculation	Gentle agitation of a water that has been coagulated to promote particle contact and formation of larger particles.
Flux	Flow rate of liquid across the membrane per membrane area.
Fouling	A reduction in water mass transfer by materials in the water, typically caused by silts and colloids.
Membrane	A highly engineered polymer film containing controlled distributions of pores. Membranes serve as a physical barrier permitting passage of materials only up to a certain size, shape, or character. Membranes are used as a separation mechanism in water treatment, laboratory, and industrial applications.
Permeate	The liquid that is transferred through (across) the membrane, i.e. the purified liquid.
Pre-treatment	The processes such as chlorination, clarification, coagulation, acidification, and degasification that may be used on the feed water to a membrane system to minimize algae growth, scaling and corrosion.
Recovery	The ratio of the permeate flow to the feed flow, generally expressed as a percentage.

Term:	Description:
Reverse Osmosis	The transport of water from a solution having a high salt concentration to one having a low salt concentration through a membrane by applying pressure to the solution having a high salt concentration. Reverse osmosis removes ionized salts, colloids, and organics down to 150Da molecular weight.
Salt rejection	The fraction (or percentage) of salt in the feed that is retained in the concentrate.
Secondary Abalone Tank Effluent	The effluent seawater from the secondary abalone tank contain increased levels of nutrient due to secretions and excretions of the living abalone as well as the feed added to the water.
Total Dissolved Solids	The sum of all dissolved solids, volatile and non-volatile
Total Organic Carbon	The sum of all organic carbon
Total Suspended Solids	The sum off all suspended un-dissolved solids
Turbidity	Any un-dissolved materials in water, such as finely divided particles of sand or clay, that reduces the penetration of light causing the water to appear cloudy.
Ultrafiltration	A process using a semi-permeable membrane under a hydraulic pressure gradient to separate suspended components in a solution. The membrane pores allows passage of the solvent but will retain non-ionic components primarily on a basis of physical size.

Term:	Description:
Water Recovery	The fraction (or percentage) of the feed water that is transferred through the membrane to the permeate side.

ABBREVIATIONS

The following abbreviations are used frequently in the report and are of importance to the reader.

Abbreviation:	Description:
ACE	annualised cost expenses
ASTM	American Society for Testing and Materials
BOO	build own operate
BOOT	build own operate transfer
BSA	bovine serum albumin
BWRO	brackish reverse osmosis
CEB	chemically enhanced backwashing
CF	concentration factor, conditioning factor
CIP	cleaning in place
CSIR	Council for Scientific and Industrial Research
DAF	dissolved air flotation
DBNPA	2,2-dibromo-3-nitrilopropionamide
DISL	daily increment in shell
DO	dissolved oxygen
DOC	dissolved organic carbon
DOM	dissolved organic matter
DON	dissolved organic nitrogen
DOP	dissolved organic phosphorous
EDTA	ethylenediaminetetraacetic acid
EfOM	effluent organic matter
EUR	Euro
FA	fulvic acid
FAN	free ammonia nitrogen
FCCDR	the fixed capital cost depreciation rate
FCR	feed conversion ratios
FF	flow factor
HA	humic acid
IP	investor's property
MFI	modified fouling index
MW	molecular weight
MWCO	molecular weight cut off
NOM	natural organic matter
NPF	normalised permeate flow/flux
NTU	nephelometric turbidity units
O&M	operation and maintenance
OM	organic matter

Abbreviation:	Description:
PCF	pressure correction factor
PER	protein efficiency rate
PESM	polyethersulfone with special additives
RO	reverse osmosis
ROSA	Reverse Osmosis System Analysis
SDI	silt density index
SGR	specific growth rates
SMBS	sodium metabisulphite
SMP	soluble microbial products
SP	salt passage
SR	salt rejection
SS	suspended solids
SWRO	seawater reverse osmosis
TAN	total ammonia nitrogen
TDS	total dissolved solids
TEP	transparent exopolymer particles
TFC	temperature correction factor
TFC	thin film composite
TMP	trans membrane pressure
TOC	total organic carbon
UF	ultrafiltration
UPC	unit production cost
USA	United States of America
USD	United States Dollar
WHO	World Health Organisation
WRF	Water Research Foundation
ZAR	South African Rand

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CHAPTER 1

1. INTRODUCTION AND MOTIVATION OF STUDY

"Water is the driving force of all nature."
- LEONARDO DA VINCI, 1452-1519

Water demand all over the world is rising because of continuous population growth and economic development. Water is the key element required to sustain social and economic growth in any country. Water can therefore become the limiting factor in further social and economic development. In South Africa in particular water is already scarce and the amount of clean, safe and potable water is decreasing every day due to the large amounts of water pollution caused by industries.

1.1 BACKGROUND

The South African abalone farming industry, based entirely on the *Haliotis Midae* (*H. Midae)* species, has been commercially cultured since about 1994 (Mouton & Gummow 2011). Although abalone is not currently one of the main components of mollusc production in the world, the industry is rapidly expanding.

According to the latest report on the *State of World Fisheries and Aquaculture* (FAO 2011) the four main components of mollusc production in 2008 were oysters (31.8 percent), carpet shells and clams (24.6 percent), mussels (12.4 percent) and scallops (10.7 percent). While mollusc production as a whole grew at an average annual rate of 3.7 percent in the period 2000–08, production of the "luxury" group of abalone increased from 2 800 tonnes to 40 800 tonnes in the same period, at an annual growth rate of 39.9 percent. During this time, total commercial production of *H. Midae* in South Africa has reached approximately 1000 tonnes per annum, mostly all from intensive pump-ashore systems (Mouton & Gummow 2011).

Nearly all South African abalone farms function on an intensive pump-ashore, flow-through system. Here large volumes of sea water flow through abalone or kelp harvesting tanks and finally gravitate back to the ocean (Mouton & Gummow 2011). Considering the rapid growth of this industry (globally, as well as locally), membrane-based desalination of abalone farm seawater effluent could possibly be more cost effective than a desalination plant with its own intake system, due to the sharing of intake facilities. Such sharing can bring about capital,

operational and energy consumption cost savings, ultimately decreasing the cost of water production through desalination. Ideally one would use the abalone effluent sea water, since this would require no increase in intake capacity for the farm.

The development of large sea water desalination plants in coastal areas emphasises the importance of selecting or designing the optimal sea water intake system that will allow the production of safe potable water at the lowest cost and impact on the environment (Voutchkov 2011). Intake systems for the abstraction of sea water are typically complex and expensive to design and install. The design and selection of these systems play a vital role in the optimization of the pre-treatment and overall plant performance and could either lower or increase the cost of water production (Hassan et al. 1999). Should the effluent water from an abalone farm therefore be of an acceptable quality for desalination, it could replace the intake system together with all related costs and complications. However, the use of effluent from abalone farms may present its own set of problems and complications and therefore require investigation.

This project focuses on determining the feasibility and viability of integrating a desalination plant with a typical South African abalone farm.

1.2 PROBLEM STATEMENT

The feasibility and viability of integrating a desalination plant with a typical South African abalone farm is uncertain. Despite the known sensitivity of abalone to water quality (Samsukal 2004) there is only a very basic understanding of water quality dynamics on South African abalone farms. The effect of abalone effluent water on reverse osmosis (RO) membrane fouling is unknown. The abalone farm operation in general is not well documented in literature. The possible cost savings of integrating an SWRO desalination plant with typical South African Abalone farm is not documented.

1.3 MOTIVATION OF THE STUDY

In 2002 already, approximately 40% of the global population suffered from serious water shortages. The increasing global population growth further complicates the matter and this percentage is expected to increase to as high as 60% by the year 2025 (El-Dessouky & Ettouney 2002).

Recent development in the South African abalone industry has led to traditional commercial abalone fisheries spreading over approximately 580 kilometres of coastline between Cape Columbine and Quoin Point as shown in Figure 1.4 (Troell et al. 2006).

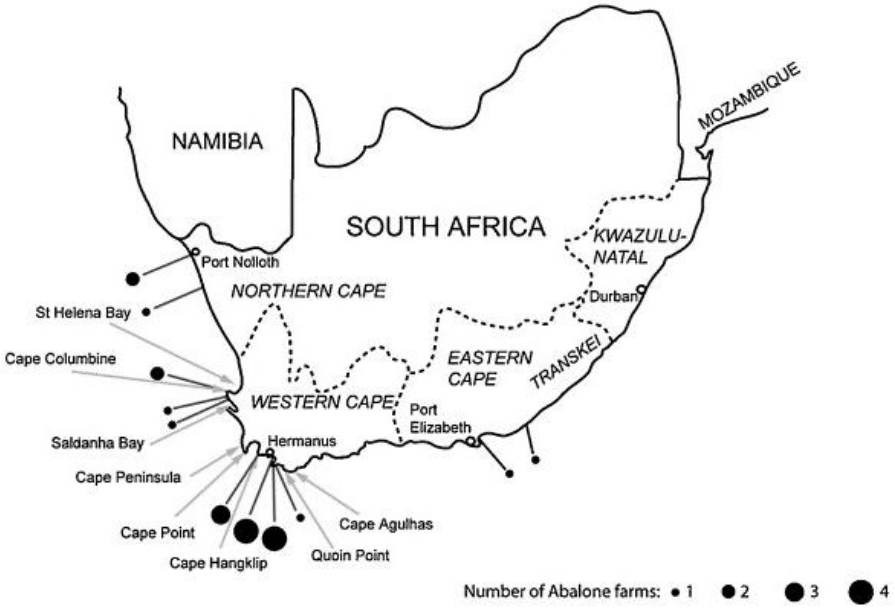

Figure 1.3 *– Abalone farm distribution on the South African coastline (adapted from Troell et al. (2006)).*

Desalination of effluent water from these abalone farms, stretching along the South African coastline, could possibly, cost effectively augment water supplies in surrounding areas. A study on the potential integration of desalination plants with typical South African abalone farms is therefore beneficial to all parties involved.

However, one needs a better understanding of abalone farm operations in general as well as abalone farm water quality dynamics and how these aspects may affect the performance of a desalination plant. Whether the abalone effluent water may cause extreme fouling on RO membranes is uncertain and a suitable pre-treatment method for the abalone effluent water should be identified. These uncertainties need to be addressed and these serve as motivation for this study. Furthermore, it is also important to estimate the possible cost savings related to a shared intake system.

1.4 AIMS/OBJECTIVES, SCOPE AND DELIVERABLES

Considering the background, problem statement and motivation for this study, the aims, objectives and tangible deliverables can now be defined.

1.4.1 Aims/objectives

This project aims to determine the feasibility and viability of cost effectively integrating a sea water reverse osmosis (SWRO) desalination plant with a typical South African abalone farm, identifying the possible challenges and suggesting probable solutions to these challenges.

In order to do this, the project focuses on four areas of concern, namely:

- Characterisation of typical South African abalone farm water
- SWRO desalination plant pilot study and membrane fouling behaviour
- General operation of a typical abalone farm and its implications for desalination
- Cost estimates and implications for the integration of an SWRO plant with an abalone farm

1.4.2 Scope and Deliverables

A typical abalone farm in Hermanus in the Western Cape, South Africa was chosen as the site. The abalone species cultivated here is the *Haliotis midae* which occurs naturally along the coast of South Africa.

Preliminary water characterisation and identification of a suitable sampling area was done for almost four months from June 2011 up to September 2011 whilst the SWRO pilot plant was still being designed and built. Actual water characterisation of forty individual abalone tanks was done for a period of approximately seven months from October 2011 to April 2012. Water characterisation of combined influent combined, effluent, ultrafiltration (UF) feed, UF permeate, RO feed, RO permeate and RO concentrate streams were done for a period of approximately four months from March 2012 to July 2012. The pilot study was also conducted for a period of six months from February 2012 up to July 2012.

The deliverables necessary to achieve the aims and objectives of this project are as follows:

- Review of applicable literature pertaining to South African abalone farming and SWRO desalination.
- Characterisation of sea water on a typical South African abalone farm and determining the effect of the abalone on the sea water pumped through such a farm.
- Designing and building an SWRO desalination pilot plant to be operated on a typical South African abalone farm to determine potential membrane fouling behaviour.
- Gain on-site experience in order to better understand abalone farm operations and implications for integration with an SWRO plant.

- Review of applicable literature pertaining to the typical capital and operational costs of an intake system for a desalination plant as required to determine the possible cost savings implicated by a shared intake system.

1.5 THESIS LAYOUT

An overview of the thesis is shown in Figure 1.5 to highlight how the different aspects of the study fit together to finally establish whether it is feasible and viable to integrate an SWRO desalination plant with a typical South African abalone farm.

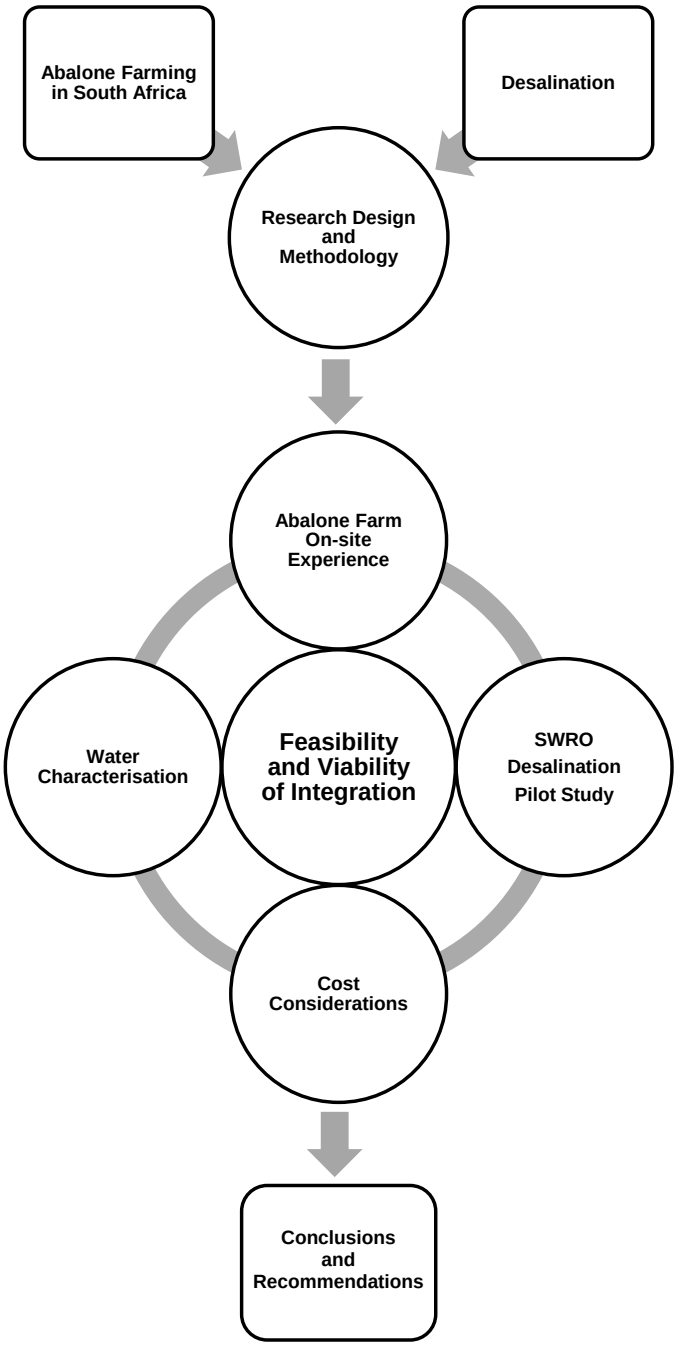

Figure 1.5 *– Thesis layout*

Chapter 2 of this thesis focuses on the abalone farming industry in South Africa, its development, management and operation as well as the available literature on abalone farm water quality. In **Chapter 3** the focus shifts to desalination. It starts with the advantages and disadvantages of the different available intake systems for sea water reverse osmosis (SWRO) desalination plants. Feed water characterisation in terms of different foulants and fouling indices is then discussed. Reverse osmosis desalination is discussed in detail, including pre-treatment alternatives, basic terms and definitions, operation, data capturing and analysis and finally membrane cleaning alternatives. Both chapters 2 and 3 provide insight and background information, as required to ensure effective operation of the pilot plant and related characterisation of water. **Chapter 4** then addresses the research design and methodology to the study. **Chapter 5** contains the results from the water characterisation and pilot plant study as well as an in-depth discussion of these results. From the on-site experience gained **Chapter 6** addresses the practical aspects to be considered when integrating an SWRO desalination plant and an abalone farm. Chapter 6 also discusses the cost considerations of the integration between these two. Finally the most important conclusions and recommendations are discussed in **chapters 7 and 8**.

CHAPTER 2

2. ABALONE FARMING IN SOUTH AFRICA

"Many estuaries [water] produce more harvestable human food per acre than the best mid-western farmland."
- STANELY A. CAIN, March 1967

The development, operation, water quality dynamics and distribution of South African abalone farms are discussed in this chapter. This offers good insight into the operation of a typical South African abalone farm and also water quality and its implication for membrane treatment.

2.1 DEVELOPMENT

South African abalone fishery has been in existence since 1949 but since 1965 strict conservation measures were implemented in South Africa to prevent the harvesting and ultimate extinction of the *Haliotis midae* species (Genade *et al.* 1988). The largest abalone harvest ever in South Africa was made in this same year with an annual harvest of 2800 tonnes of abalone. A maximum annual harvest of 386 tonnes was then imposed in 1968, and reduced to 227 tonnes in 1970 (Tarr 1995). This production quota was even further reduced to 181 tonnes in 1971 and by another ten percent to 163 tonnes in 1982 due to continued concern over the state of the resource. Despite these strict conservation measures, South African abalone was brought to near extinction as a consequence of years of uncontrolled fishing and poaching. This led to the complete ban on abalone fishing issued by the Department of Environmental Affairs and Tourism of South Africa in 2008. However in 2010 this ban was conditionally lifted by the cabinet in June 2010 (Van der Merwe 2010)

Fuelled by these conservation measures, abalone cultivation started in 1981 through successfully spawning captured specimens to produce spat and juvenile abalone (Genade et al. 1988; Sales & P J Britz 2001). Proving that the South African abalone (*Haliotis mdae*) could be reared and spawned in captivity (Genade et al. 1988) this provided a platform for the South African abalone industry and set its development into motion. Initial research even indicated faster growth rates in captivity than in the wild. Food conversion efficiencies were of such a nature that the locally available kelp quantities would be sufficient to feed the farm stock (Hahn 1989). Although the stage was now set for the rapid development of the

abalone farming industry in South Africa, abalone farming only really became an established industry in the 1990s with the first ten tons of abalone being produced in 1997.

Since 2001 twelve abalone farms have been established on the coast of South Africa, with a combined estimated investment of 12 million USD and projected production of 500-800 tonnes per year (Sales & P J Britz 2001). The South African abalone industry has grown to such an extent that it has surpassed this projected production already by 2005 (FAO 2011) increasing steadily to approximately 1000 tons in 2008 with a market value of almost 35 million USD (FAO 2011). Today the South African abalone industry is still growing rapidly and is currently the largest producer outside of Asia. While most of the farms are located in the Western Cape – most notably along the South coast between Hermanus and Danger Point, and around the Saldanha Bay / St Helena Bay area on the West coast – farms are also located as far north as Port Nolloth in the Northern Cape, and as far east as Haga-Haga in the Eastern Cape (Figure 1.4).

To date, abalone culture in South Africa has been developed as a land based activity that employs pump-ashore technology, combined with intensive flow-through or recirculation culture systems. Over the past 15 years, considerable efforts have been made to develop appropriate culture technologies for the species. Most notably, research efforts have focused on issues pertaining to system design, reproduction, nutrition and the development of artificial feeds, and disease control. The reproductive cycle of these molluscs has been closed, and the technology for their artificial spawning has been developed. As such, spat are hatchery-reared and grown out in tank systems. Spat are initially reared on algal films, and once large enough, they are weaned onto a macro algal or formulated diet (or a combination of the two). Typically, the abalone are harvested at a cocktail size (± 80 – 90 mm shell length), reaching maturity within 3 to 4 years. The majority of the farms have developed their own hatchery operations, and by 2000, eleven of the twelve farms that were in operation had their own hatchery.

2.2 ABALONE BREEDING AND CULTURING

2.2.1 South African Species

Abalone are marine gastropods that belong to the *Haliotis* genus. *Haliotis* is the only genus of the family *Haliotidae* from the phylum *Mollusca* (Barkai & Griffiths 1986). The latest figures indicate that there are approximately 90 *Haliotis* species worldwide (Sales & P J Britz 2001). Six *Haliotis* species are endemic to South Africa, *H. midae*, *H. parvum L.*, *H. spadicea*, *H. queketti*, *H. speciosa* and *H. pustalata. O*nly the *H. midae species,* known locally as ‘perlemoen’, is cultivated and of commercial significance (Muller 1986; Sales & P J

Britz 2001). The other five species are relatively small and not harvested commercially (Van der Merwe 2010).

2.2.2 Spawning and Seed Production

The successful spawning of captured specimens to produce spat and juvenile abalone was achieved by Genade and other and can mainly be attributed to luck since *H. midae* will usually not spawn when collected ripe from the wild (Genade *et al.* 1988). The abalone collected by Genade spawned unexpectedly in the bag that they were collected in after which the viable larvae were settled at laboratories in Knysna (Sales & P J Britz 2001). Hatcheries therefore had to develop offspring stock protocols and maintain a hatchery offspring stock population which could be spawned on a regular basis (Sales & P J Britz 2001).

Tarr (1995) showed in his study of abalone at six different sites along the South African coast (Dassen Island, Robben Island, Betty's Bay, Mudge Point, Danger Point and Bird Island) that *H. midae* may reach 100% sexual maturity at approximately 7.2 years which is about 4 years earlier than previously estimated by Newman (1967). In captivity this time required for the abalone to reach sexual maturity has been reduced to only 4 years due to the optimal conditions induced on these farms. Spawning occurs twice a year, during spring and autumn, with variations owing to locality (sea temperature, substrate, food availability *etcetera*) (Sales & P J Britz 2001).

2.2.3 Growth

Abalone farming is both expensive and time consuming due to the slow growth rate of the *Haliotis* species (Britz 1996). In the wild, *H. midae* can take as long as 30 years to reach its maximum growth of approximately 200mm shell length (Tarr 1995). High variability is found in wild animal growth rates for different sites along the South African coast. This is due to varying conditions such as sea temperature, substrate, and food availability.

Some of the many conditions influencing growth rates during trial conditions are the initial size of molluscs, stocking density, temperature and duration of the trial. In a study by Dlaza on the growth of post-weaning abalone (*Haliotis midae linnaeus*) on various formulated feeds, fortified with fresh wild seaweed, it was proven that animal-based protein feeds yield better growth rates than seaweed-based protein feeds (Dlaza 2006). Fortifying these feeds led to even better growth rates. Various sampling and data collection methods exist with regards to the growth of abalone; the methods used most often are discussed here.

2.2.3.1 Daily Increment in Shell Length

The average daily increment in shell (DISL) length ranged from 65.30 ± 0.2 µm.day^{-1} for molluscs on a high carbohydrate diet to 27.40 ± 0.2 µm.day^{-1} for molluscs on a low protein and carbohydrate diet (Dlaza 2006). DISL is determined by means of equation 2.2.3.1.

$$\boldsymbol{DISL(\mu m/day) = [(SL_t - SL_i)/t] \times 100} \qquad \textit{equation 2.2.3.1}$$

where

SL_t shell length at time t

SL_i initial shell length

t growth period

2.2.3.2 Specific Growth Rate

The specific growth rates (SGR) determined by Dlaza ranged from 0.49 ±0.2% weight/day^{-} for molluscs on a low protein diet to 1.05 ±0.2 %weight/day for molluscs an a high protein diet fortified with fresh kelp and ulva (Abfeed® + kelp and ulva). Specific growth rates in between these two values were obtained for different feed compositions. SGR is determined by means of equation 2.2.3.2.

$$\boldsymbol{SGR\ (\%\ body\ weight/day) = [ln(W_t) - ln(W_i)]/t \times 100} \qquad \textit{equation 2.2.3.2}$$

where

W_t abalone body weight at time t

W_i initial abalone body weight

t growth period

2.2.3.3 Conditioning Factor

The conditioning factor (CF) ranged from 0.864g.mm^{-1} for the low protein diet to 1.447g.mm^{-1} for the fortified high protein Abfeed® diet. The CF is determined by means of equation 2.2.3.3.

$$\boldsymbol{CF\ (g.mm^{-1}) = [W(g)/\ SL(mm)^{2.99}] \times 5575} \qquad \textit{equation 2.2.3.3}$$

2.2.4 Temperature

Temperature is one of the most important environmental factors that determine the metabolic rate of poikilothermic animals (Yearsley 2008). South African abalone is distributed from the cold waters of the Benguela current on the Western Cape Coast of South Africa to the warmer waters of the of the Eastern Cape Coast. The water temperature therefore varies from a minimum of 12-13°C to a maximum of 21°C (Britz & Hecht 1997). In natural stocks an inverse relationship between maximum abalone size and average sea temperature was proven to exist by Tarr among others (Tarr 1995). The physiological optimal temperature for *Haliotis midae* ranges between 12-20°C (Britz & Hecht 1997). Above 20 °C growth rates declined, protein efficiency rate (PER) and feed conversion ratios (FCR) declined and mortality rates increased (Britz & Hecht 1997)

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2.2.5 Handling and Transport

Abalone is renowned for their ability to rapidly pull down their shells tightly onto the substratum, making it very difficult to remove them. Mechanical removal tends to injure or kill them due to their slow recovery rates and increased probability of stress and bacterial infections (Sales & Britz 2001). Various studies evaluating the suitability of local anaesthetic were therefore initiated and it was found that magnesium sulphate could be used as an effective and safe anaesthetic on *H. midae* (Sales & Britz 2001). Carbon dioxide gas is also sometimes used to sedate the animals when handling them.

H. midae is sensitive to transport and should not be in transit for more than 36 hours. Although juvenile abalone can survive up to 52 hours, the mortality rate increases drastically with time. Oxygen enrichment is used during transit to alleviate stress and reduce mortalities. Temperature fluctuations should be kept to a minimum and containers should be kept very humid to prevent damage to the gills of the abalone.

2.2.6 Nutrition

Haliotis midae is a herbivorous mollusc that naturally feeds on algae and has a nocturnal pattern of feeding (Sales & Britz 2001). Abalone feeds mainly on yolk at the larval stage. The larval stage is 5 to 7 days (20°C to 17.5°C) after which the larvae settle down in shallow water to become post-larval juveniles feeding on benthic diatoms (Sales & Britz 2001; Dlaza 2006). As the larvae grow larger the live food organisms are replaced with a formulated diet in order to achieve higher growth rates due to the higher nutritional value of the formulated diets (Dlaza 2006). This process is known as weaning. Several abalone feeding alternatives exist and can be divided into the following broad categories (Troell *et al.* 2006):

Seaweed-based pellets

In South Africa the only currently available seaweed-based pellet (all-seaweed) is called *Midae Meal MM-1c* (Eric-Piet (Pty) Ltd, Luderitzbucht Namibia) and is being manufactured for *Tuarus Products* (Pty) Ltd. These formulated pellets consist of the following species of seaweed – mainly *Laminaria spp*. and *E. maxima* with smaller amounts of *Graciliaria spp*., *Gelidium spp*., *Porphyra capensis* and *"agar-agar"*. Wet seaweed to dry pellet weight ratio is approximately 7:1 with a protein content of 18% (Troell *et al.* 2006).

Kelp pellets

Although abalone prefers fresh kelp there are two companies known to produce and test dried kelp pellets. The two South African companies are *Taurus Products (Pty) Ltd., Rivonia* and *Kelp Products (Pty) Ltd, Simon's Town* (Troell *et al.* 2006).

Abfeed™ (Marifeed Pty Ltd, South Africa)

In a study on the influence of diet on the growth of abalone (Dlaza 2006), Abfeed™ outperformed several other formulated feeds, and was established as the best formulated feed for South African abalone, *Haliotis midae*. In this same study which was consistent with previous work it was shown that animal-based protein feeds yield better growth rates than seaweed-based protein feeds. The study also investigated fortifying formulated feeds with fresh wild seaweed and this gave the best growth rates by far. Abfeed™ contains mainly soya bean meal, fishmeal, starch, vitamins and minerals. These substances give it the following nutritional breakdown: 35% protein, 43% carbohydrates, 5% fat, 1% crude fibre, 6% ash and 10% moisture. A cheaper form of Abfeed™ (K26) that contains less protein (26%) is also produced and fed mainly to larger, stronger abalone (> 50mm shell length) (Troell *et al.* 2006).

Other seaweed species

Graciliria, *gelidium*, *ulva*, *porphyra* and *ecklonia* are other seaweed species that are currently being used as feed to abalone. These seaweed species are used in very low quantities and usually only fed to abalone in the hatchery (broodstock). This is due either to the low natural quantities or the erratic supply.

It is important to realise that a large quantity of the feed will remain suspended in the abalone tanks or end up in the effluent streams which could affect the desalination thereof.

2.3 ABALONE FARM MANAGEMENT AND OPERATION

The general management and operation of the abalone farm is established before commencing the pilot study to ensure as little as possible interruptions to the smooth operation of the SWRO desalination pilot plant. Abalone farm operations that could influence the SWRO desalination pilot plant and therefore also a commercial scale SWRO desalination plant are discussed here. The unforeseen events and on-site experience will be discussed in chapter 6 of this dissertation.

2.3.1 Physical Setup

South African abalone farms make use of pump-ashore technology combined with intensive flow-through or recirculation culture systems. Raw sea water from the culture systems typically flow back to the sea under gravity. During the grow-out phase of the abalone production process abalone is kept in baskets suspended in tanks through which the sea water flows. The tanks can be made of concrete (longest life span, largest capital investment) or other materials such as polypropylene (shortest lifespan, smallest capital investment). Each tank typically contains 12 (two rows of 6) or 16 (two rows of 8) baskets with molluscs.

The abalone farm, with which this thesis concerns itself, uses concrete tanks with two rows of 8 baskets each. Each basket holds approximately 15 kg of live abalone mass. Each half of a tank has an approximate volume of 2880 litres each. Water flows through the tanks at an average rate of 20 litre/kg/h giving 2400 litre/h for each half or 4800 litre/h per tank.

Figure 2.3.1 provides a schematic diagram of an abalone cultivation tank. Influent sea water enters the tank at the water-surface (1) and leaves the tank by means of a standing pipe outlet (2) situated at the opposite end of the tank. This tank contains sixteen mesh abalone baskets (3) each with vertical plates/racks (4) to increase the surface area on which the abalone can move and grow. An aeration plate is found at the bottom of each tank (5). The cultivation abalone population density is approximately 3.05 kg/m^2. This is much higher than the 82 – 133 g/m^2 found in the wild (Barkai & Griffiths 1986). Under these conditions the water in the culture environment may become altered to such a degree that it influences and even poisons the abalone itself. Furthermore the sea water can be altered and affected in such a manner that it affects a desalination process in an adverse manner.

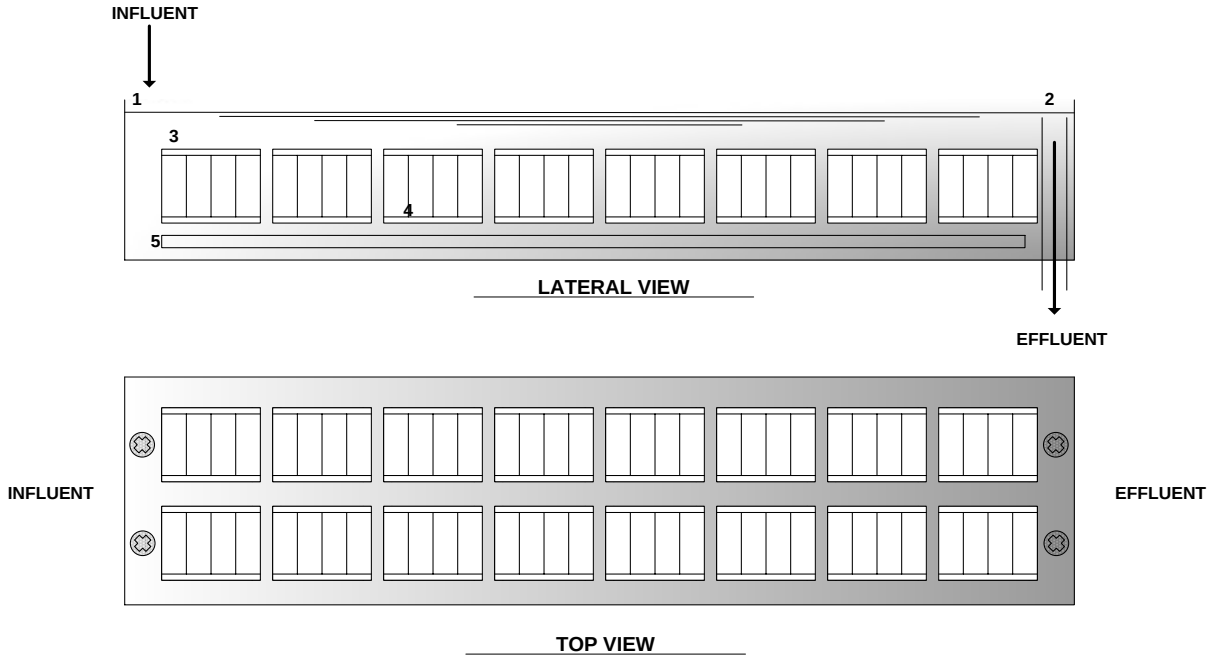

Figure 2.3.1 *– Lateral and top view of a typical abalone cultivation tank*

2.3.2 Process Flow Diagram

In any abalone farm there is a degree of pre-treatment of the raw sea water before it enters the abalone tanks where the abalone is cultivated. Figure 2.3.2 shows a schematic representation of the water process flow in a typical abalone farm.

First the raw sea water is allowed to flow through a screen or kelp catcher which serves to filter anything larger than approximately 5 mm. This includes anything from crustaceans, fish, kelp, coarse sand/rocks to even people. The water flows through this screen into a primary sump which acts as a type of reservoir where the remaining solids are allowed to settle down and from where the water can be pumped by the primary set of pumps. The water is pumped to a secondary sump while the solids are removed to the ocean. From the secondary sump the water is pumped through a pair of primary drum filters which have a nominal rejection size of approximately 1000 µm (1 mm). From here the water flows to another secondary sump. The water is then pumped directly to the abalone tanks and to the pre-treatment stage for the hatchery tanks. The water which flows to the hatchery is further filtered by another pair of secondary drum filters with a nominal rejection size of approximately 28 µm each. Then the water is put through four foam fractionators for final removal of some of the larger dissolved substances such as some proteins. This water is then stored in tanks from where it is either pumped directly to the hatchery tanks or to the hatchery tanks via heaters – depending on the temperature requirements.

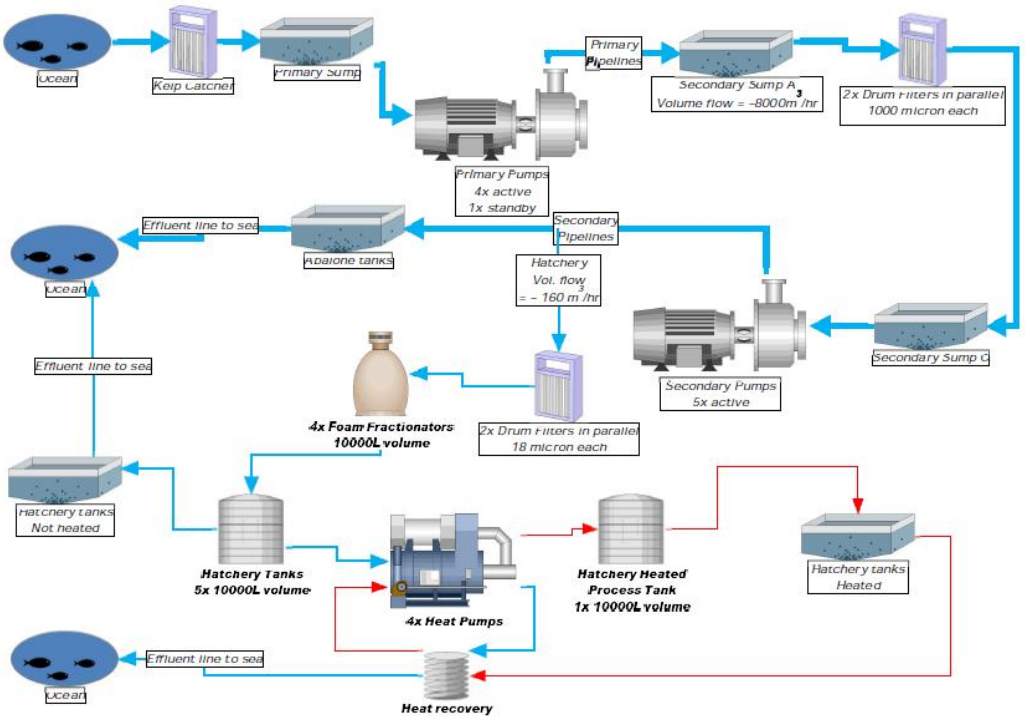

Figure 2.3.2 *– Process flow diagram of a typical South African abalone farm*

2.3.3 Sea water Flow

The flow of sea water unto the farm should be continuous and water down-time refers to any time that sea water is not flowing through the farm. Water flow should preferably not be interrupted for more than two hours per week, excluding down-time scheduled for maintenance operations, due to the adverse effect of water down-time on abalone mortality rates. Unfortunately, it may happen that there is down-time of up to twenty hours a week, if equipment such as the kelp catchers or drum filters break. Other unforeseen eventualities that may cause water down-times are related to the oceanic conditions at the intake system – such as the presence of red bait and red tide which are seasonal occurrences which cannot precisely be predicted. Power generators are used to prevent water down time due to power failure.

Water flow rates on abalone farms typically range between 15 – 25 litre/kg/h. Flow rates less than 18 litre/kg/h are avoided at all cost since this is detrimental to the health of the abalone. The flow rates on the abalone farm where the pilot study is performed are similar to these typical values.

2.3.4 Sump Cleaning

A primary sump is typically directly connected to the ocean, separated only by the kelp catcher which is not routinely cleaned. The kelp catcher can occasionally be cleaned as it becomes blocked from time to time. The secondary sumps are scheduled for cleaning once every two weeks. Depending on the weather conditions as well as the condition of the ocean this process may be done more often. Also if the water down-time limit of 2 hours per week has been exceeded the health of the abalone will not be risked in order to clean the sump. The sump will then not be cleaned during that week.

The process entails draining the sumps and removing excess sand, grit or anything else that might have gone through the primary pumps and passed the drum filters. The process usually takes about 2 hours.

2.3.5 Cleaning of Main Pipe Lines

The main pipelines are 'pigged' once every week. The 'pigs' that are used are made of a hard sponge-like material and are sent through the pipelines using the water pressure. This could also be done more often if the pipes are badly blocked due to excessive growth of barnacles, grit or for any other possible reason. Again the lines will not be pigged if the water down time limit has been exceeded due to other unforeseen reasons. This process takes anything from 30 minutes to an hour and is typically done after cleaning the sump (if the sump is cleaned during the same week).

2.3.6 Cleaning of Secondary Lines

The smaller pipe lines branching from the main lines are too small to be 'pigged' and are cleaned using specialised high pressure hoses. This is done in order to clean the pipes of anything growing inside as well as dirt and grit that passes the drum filters and get stuck in these lines causing blockages and in turn lowers water flow rates. The cleaning of the secondary pipelines is only done once a month. The cleaning for each line can be done separately and the water for each line can be switched off separately – it therefore only causes water down-time per secondary pipeline of about 10 minutes.

2.3.7 Abalone Feeding Strategy

The abalone is fed a combination of Abfeed^{TM}, *ulva spp.* and kelp. The formulated pellets are fed daily at a rate dependent on the amount of *ulva spp.* and kelp fed during the same period. The *ulva spp.* and kelp are fed according to the availability thereof. Kelp is typically available once a week and it is fed as fresh as possible since it goes down rather quickly. *Ulva spp.* is fed less often.

2.3.8 Abalone Tank Cleaning Strategy

The abalone tanks are cleaned once a week. A worker can clean on average two rows (4 lines of 10 tanks each) per day if this is all they are working on.

Each worker is responsible for two rows, this includes cleaning and feeding and checking of the lines. As mentioned, cleaning is unfortunately interrupted by other duties such as kelp feeding, cleaning of the sump, 'pigging' of the lines and feeding – this slows down the pace at which they clean.

Currently the sea water overflow (during normal operation) and the dirty cleaning water (during cleaning operation) use the same channel on most farms. This means that during cleaning the inlet pump for the desalination pilot plant will have to be switched off and a buffer tank will be required. The water is too dirty and full of suspended solids to use whilst cleaning operations are performed. In future developments the dirty flushed sea water should preferably be diverted from the cleaner sea water from the tanks' overflows and removed separately. This may simplify the integration of an SWRO desalination plant and abalone farm.

2.3.9 Animal Sorting Strategy

Once every four months abalone is sorted – they are then removed completely from the tanks and the tanks are scrubbed thoroughly. This entails cleaning with chlorine and a scraper to remove any barnacles or other animals growing on the inside of the concrete tanks. Although the effluent from these tanks are diluted to a very low concentration, the chlorine could pose a risk to the cellulose acetate reverse osmosis membranes, sodium metabisulfite (SMBS) must therefore be used to remove any residual chlorine.

The abalone typically grow from 12 kg/basket to about 16 kg/basket in four months' time. Once the abalone has reached this mark it is resorted – the abalone that has grown past the size limit for the farm are moved to other farms where it matures further. The abalone that are small enough are resorted into 12 kg per basket and placed back into the system.

2.4 ABALONE FARM WATER QUALITY

In spite of the industrial scale of abalone farming in South Africa, few studies have investigated the water quality on abalone farms. Also the few studies that were done focused mainly on the effect of water quality on the abalone with regards to toxicity, growth, maximum size, mortality *etcetera*. This study is concerned with whether or not it is feasible to desalinate effluent water from typical South African abalone farms. To determine this, additional parameters need to be measured.

A review of three research studies done on abalone farming is provided here to shed some light on the water quality dynamics in typical abalone farms. Many of the conditions influencing the parameters such as feed frequency, population density, water flow rate through the abalone tanks, abalone size, water temperature, *etcetera* differed. The data from these three studies cannot be compared directly. Each study is treated and discussed individually to highlight all valuable information.

2.4.1 Investigation by Pamela Samsukal (Samsukal 2004)

2.4.1.1 Objective

In her MSc study Pamela Samsukal conducted a preliminary study of effluent water quality on land-based abalone farms in South Africa.

2.4.1.2 Scope

The study was conducted on seven farms from June to July 2003 in Hermanus and Gansbaai on the South Coast and Paternoster on the West Coast of South Africa. The total annual production of the farms under investigation, ranged from 40 to 100 tonnes. In general, nursery juveniles were fed diatoms. Formulated feed was used for younger stages and still growing abalone were fed kelp (*Ecklonia maxima*) occasionally supplemented with macro algae (*Gracillaria spp.* and *ulva spp.*). Effluent water quality was determined during standard farm operations as well as during cleaning operations.

2.4.1.3 Results

The results from this study can only serve as a broad indication of what can be expected of the typical water quality of the effluent on the farm that this project concerns itself with. This was only a preliminary study and the effluents sampled vary significantly in origin from farm to farm. Some of the effluent for example contains water from the hatchery, others from grow-out tanks; some even consist of a mixture. The filter treatment before and after the abalone tanks also differ from farm to farm. The range of water quality variables taken is summarised in Table 2.4.1.

Table 2.4.1– *Range in effluent water quality variables on a typical South African abalone farms (adapted from Samsukal (2004))*

Nutrients	**µmol N (P) / litre**	**µg N (P) / litre**
Ammonium (NH_4)	*0.44 – 19.25*	*0.03 – 1.38*
Nitrite (NO_2)	*0.15 – 1.10*	*0.01 – 0.08*
Nitrate (NO_3)	*4.92 – 21.71*	*0.35 – 1.55*
Inorganic Phosphate (PO_4)	*0.65 – 6.04*	*0.02 – 0.20*
Dissolved Organic Nitrogen (DON)	*0.00 – 14.25*	*0.00 – 1.02*
Dissolved Organic Phosphorous (DOP)	*0.00 – 1.86*	*0.00 – 0.06*
Suspended Solids (SS)		**mg/litre**
>63µm		*3.24 – 18.80*
<63µm		*0.71 – 21.10*

2.4.2 Investigation by Rowan Yearsley (Yearsley 2008)

2.4.2.1 Objective

In his MSc study Rowan Yearsley investigated the following aspects:

- Effect of water quality at different positions within abalone tanks on abalone growth.
- Diurnal changes in influent and effluent water quality.
- Seasonal changes in the quality of abalone farm influent and effluent water.

The main aim was to describe water quality dynamics and identify water quality variables that can affect abalone growth in typical South African abalone farms.

2.4.2.2 Scope

The farm under investigation was the HIK Abalone Farm (Pty) Ltd in Hermanus. The farm had a standing stock of 110 – 126 tonnes. Abalone was grown to 20 – 120 g before sale and fed a formulated diet (Abfeed™). Abalone was grown in baskets suspended in tanks with a flow through sea water system at ambient temperature. The average flow rate through the farm was 6.9 $\pm$ 1.8 litre/s/tonne (24.84 $\pm$ 6.48 litre/kg/h). Air diffusers were used to improve water mixing and sediment from tank bottoms was removed every 10 days.

2.4.2.3 Results

Ten samples were taken every month, over a period of twelve months (June ’06 – May ’07), half of which were collected at 09:00 and the other half at 16:00. The results obtained by *Yearsley* are summarised in Table 2.4.2.

Table 2.4.2 *– Range in influent and effluent water quality variables on a typical South African abalone farms (adapted from Yearsley (2008))*

	09:00		16:00	
	mean	**standard error**	**mean**	**standard error**
Inflow				
Temperature (°C)	*14.91*	*0.25*	*15.61*	*0.26*
pH	*8.06*	*8.04 – 8.08*	*8.13*	*8.12 – 8.15*
Dissolved oxygen (DO) (mg O_2/litre)	*8.17*	*0.07*	*8.16*	*0.09*
Total ammonia nitrogen (TAN) (µg TAN/litre)	*18.23*	*0.75*	*18.26*	*1.14*
Free ammonia nitrogen (FAN) (µg FAN/litre)	*0.46*	*0.03*	*0.57*	*0.04*
Nitrite (µg NO_2-N/litre)	*3.44*	*0.32*	*5.18*	*0.40*
Total Suspended Solids (TSS) (mg/litre)	*3.93*	*0.47*	*3.39*	*0.45*
Outflow				
Temperature (°C)	*15.04*	*0.28*	*15.94*	*0.26*
pH	*7.90*	*7.89 – 7.92*	*7.95*	*7.94 – 7.96*
DO (mg O_2/litre)	*7.42*	*0.07*	*7.20*	*0.07*
TAN (µg TAN/litre)	*55.62*	*2.65*	*60.98*	*3.36*
FAN (µg FAN/litre)	*0.98*	*0.07*	*1.32*	*0.11*
Nitrite (µg NO_2-N/litre)	*6.76*	*0.39*	*8.71*	*0.46*
TSS (mg/litre)	*8.36*	*0.87*	*5.03*	*0.52*
Production				
H^+ ion (nmol s^{-1} t^{-1} $farm^{-1}$)	*27.18*	*2.18*	*26.19*	*2.15*
TAN (µg TAN/litre)	*0.27*	*0.02*	*0.29*	*0.03*
Nitrite (µg NO_2-N/litre)	*0.02*	*0.00*	*0.02*	*0.00*
TSS (µg/s/kg)	*25.05*	*5.73*	*6.89*	*4.79*

2.4.3 Investigation by Matthew Naylor (Naylor et al. 2010)

2.4.3.1 Objective

Matthew Naylor and colleagues investigated the change in water quality between tanks in a serial-use raceway system with seven passes. They then related it to cumulative biomass and water flow rate estimating the flow index (litre/kg/h) at which growth was reduced to 60 – 70 mm for the *H. midae* species.

Although most South African abalone farms use flow-through systems, this experimental setup was selected with the aim of quantifying the effects of decreasing water quality (with consecutive tanks in series) on the growth and health of abalone. The water quality parameters of the water leaving the first tank are comparable to that of a flow through setup.

2.4.3.2 Scope

The farm under investigation was the HIK Abalone Farm (Pty) Ltd in Hermanus. The farm was investigated over a period of four months (Sept '08 – Dec '08). Abalone was grown in three serial-use raceways containing seven tanks (0.9×0.6×0.6 m) each at a varying height in order for the water to flow from one tank to the next under gravity. Filtered sea water (100 µm) entered the first tank of each raceway and proceeded to the following six tanks consecutively. Each basket initially contained 8.1±0.1 kg of abalone (approximately 165 abalone), giving a very high population density of 25 kg/m^2. Abalone was fed a formulated diet (Abfeed™) and grown for 101 days. Tanks were cleaned every fourteen days.

The initial and final flow indices through the first tank were 34.3±1.38 litre/kg/h and 28.0±1.01 litre/kg/h respectively, which was slightly higher than that for the study done by *Yearsley*.

2.4.3.3 Results

Samples were taken at 09:00 and 10:00 to achieve a reliable estimate of daily averages based on the results obtained by Yearsley (2008). The results obtained by Naylor *et al.* (2010) are summarised in Table 2.4.3.

Table 2.4.3 *– Range in influent and effluent water quality variables on a typical South African abalone farms (Naylor et al. 2010).*

	mean	standard error	range
Inflow			
Temperature (°C)	*15.10*	*1.30*	*11.30 – 17.30*
pH	*7.96*	*0.00*	*7.69 – 8.19*
DO (mg O_2/litre)	*8.45*	*0.35*	*7.89 – 9.31*
TAN (µg TAN/litre)	*8.73*	*5.14*	*0.60 – 18.60*
FAN (µg FAN/litre)	*0.19*	*0.14*	*0.01 – 0.45*
Nitrite (µg NO_2-N/litre)	*6.11*	*2.09*	*2.10 – 11.40*
TSS (mg/litre)	*6.06*	*2.97*	*1.34 – 15.63*
Outflow			
Temperature (°C)	*15.20*	*1.20*	-
pH	*7.86*	*0.00*	*7.73 – 8.02*
DO (mg O_2/litre)	*8.07*	-	-
TAN (µg TAN/litre)	*40.70*	*20.58*	-
FAN (µg FAN/litre)	*0.70*	-	-
Nitrite (µg NO_2-N/litre)	*9.86*	*4.17*	*2.73 – 23.07*
TSS (mg/litre)	*4.20*	*2.00*	-

2.5 Summary

From the literature on the South African abalone farming industry the following aspects are important for this study and should be highlighted:

- The South African abalone industry is a rapidly growing industry spreading over a large part of the South African coastline. It has the potential to reduce the cost of fresh water production via integration with SWRO desalination plants.

- South African abalone farms make use of pump-ashore technology combined with intensive flow-through culture systems. The water is filtered before being pumped to the abalone tanks. The abalone tanks are comparable to typical settling tanks. The abalone water should be of better quality than raw sea water except for the components added to the water by what the abalone excrete or secrete as well as the feed supplied to the abalone. The effect of these components on water quality and membrane fouling behaviour must be investigated.

- Seasonal changes can have a significant effect on the quality of water produced by the abalone farm intake system. The water characterisation and pilot studies must therefore be done over an extended period including seasonal changes.

- Typical operation and management procedures on an abalone farm include sump cleaning, pipe cleaning (or ‘pigging’), feeding of the abalone, abalone tank cleaning and animal sorting. The operation and management of an abalone farm must be taken into account when integrating it with an SWRO desalination plant. On-site experience on a typical South African abalone farm is required for a better understanding of the operation and management of such a farm. On-site experience will also help to identify possible events that may hinder such an integration process.

From the abalone farm water quality studies in literature it is clear that the variability in investigation does not allow for direct comparison of data between the results from the different studies. In short, the qualitative effect of the abalone on the water is the following, as deduced from the results from the three case studies available in literature:

- pH decreases through the tanks
- DO decreases as it is consumed by the abalone
- TAN increases whilst FAN decreases in some cases and increases in others
- TSS increase or decrease depending on cleaning and feeding strategy
- Nitrite increases through the abalone tanks

When considering the high flow rate of sea water through the tanks as compared to the concentration levels of the foulants or substances in the water, it should not have a remarkable effect on the quality of the water. On the other hand, very small quantities of certain foulants may cause notable fouling of ultrafiltration and reverse osmosis membranes and it is necessary to do on-site water characterisation and pilot plant tests.

CHAPTER 3

3. DESALINATION

"All the water that will ever be, is right now."
- NATIONAL GEOGRAPHIC, October 1993

Desalination has been researched for decades and an endless amount of literature is available on this topic. The aim of this literature review is therefore not to repeat this literature but rather to shed light on the aspects of desalination that will play a part in the integration of an SWRO desalination plant with a typical South African abalone farm.

3.1 INTRODUCTION

The original idea to desalinate sea water has had humankind thinking for hundreds, if not thousands, of years. The original principle was based on the idea that boiling or evaporating saltwater separated the fresh water from the salt. This theory of vaporization or distillation therefore became the technology for the first commercial scale desalination plants – which sprouted mainly in arid desert areas in the 1950s and 1960s. In the 1960s researchers mostly from the United States of America (USA) and Japan realized that they could use the semi-permeable man-made membranes, developed for industrial purposes, in desalination. By the 1970s developers started to adopt RO for use in desalination plants. The rest is history – the RO process developed rapidly and is still being developed today in order to obtain a cost effective way of desalination – especially in countries like South Africa where fossil fuels are expensive and thermal processes are less viable.

RO desalination will be applied in this study; the discussion will therefore focus on this. The following topics are discussed:

- Intake systems for SWRO desalination plants
- Characterisation of the SWRO pilot plant feed water
- Pre-treatment alternatives for the characterised feed water
- RO desalination of the pre-treated water
- Characterisation of membrane fouling

3.2 SWRO DESALINATION PLANT INTAKE SYSTEM

The intake system design determines the quantity and quality of the feed water entering a desalination plant and must balance the needs and values of the ecosystem, local community and the desalination plant. Selecting the appropriate technology for developing sea water intake system requires a variety of information from several sources to determine feasibility and viability. These include the following (Mackey *et al.* 2011):

- location and site conditions
- available technology options
- permitting requirements
- environmental impacts
- stakeholder values
- utility constraints and interests

The quality of the water in turn plays a significant role in the type and amount of pre-treatment required prior to the reverse osmosis process. The two main types of raw sea water intake systems are as follows (Alvarado 2008; Mackey *et al.* 2011):

- Surface or open intake systems
    - Shoreline intake systems
        - Direct (open) intake
        - Screened intake
    - Off-shore (deep) intake systems
        - Direct (open) intake
        - Screened intake

- Subsurface intake systems
    - Vertical(beach/coastal) intake system
    - Horizontal directional drilled intake system

3.2.1 Surface or Open Intake Systems

3.2.1.1 Shoreline Intake Systems

Shoreline direct and screened intake systems are the simplest intake systems available. They can be as simple as dredged channels through a region close to the shore from where one draws raw sea water. Though used in the past these are now seldom used, due to many technical disadvantages. These systems typically provide low quality feed water – thus resulting in unforeseen and non-programmed stops with many inconveniences and high

cost. Shoreline intake systems also have the further disadvantage of an eco-unfriendly impact in the seashore leading to environmental issues.

The main advantages and disadvantages of these systems are as follows (Wiertz & Gecamin Ltd. 2008; Mackey et al. 2011):

Advantages

- Low capital investment for the intake system
- Guaranteed permanent sea water feed flow
- Flexible capacity
- Able to meet any required capacity: high sea water flow is possible thus these intake system are preferred for large plants
- Basic framework for the design of shoreline intake systems is well documented with many references.

Disadvantages

- Low feed water quality.
- Complex pre-treatment required for low quality feed water.
- High colloids, TSS, total organic carbon (TOC), oil and grease content.
- Low feed water quality and complex pre-treatment add significantly to the overall capital and operational and maintenance costs.
- Subject to corrosion, plugging, biological growth, erosion, wave activity and storm effects that affects performance, service life, operation and maintenance (O&M) requirements, and sustainability.
- There will be an increased focus on the environmental protection aspects of the intake system as the intake screening devices do not remove all the organisms within the water source during the intake process. Licensing and authorization are difficult to obtain for this type of intake system due to their eco-unfriendly nature.

3.2.1.2 Off-shore Intake Systems

The off-shore (deep) sea intake system is more sophisticated than the shoreline intake system. Pipelines are constructed from the shore to beyond the near shore up to where the water is approximately 35m deep. The reason for this is that deeper water is less affected by tidal action and waves. Additional pumping and pipeline costs finally limit the depth in which these intakes can practically be placed. Deep sea intakes have a service life of 30-50 years, making them an attractive option. Deep sea intakes also supply unlimited amounts of raw sea water to desalination plants as it is pumped directly to the plant (Wiertz & Gecamin Ltd. 2008).

Multiple plastic pipes are typically used in large desalination plants – this allows working with smaller diameter pipes. The submarine works to install these pipes are complicated, specialised and therefore very expensive. The main advantages and disadvantages of these systems are the following (Wiertz & Gecamin Ltd. 2008; Mackey *et al.* 2011):

Advantages

- Low impact on beach and shore environment
- Large capacity for water flow
- Permanent sea water flow guaranteed

Disadvantages

- Studies required prior to instalment (cartographic)
- High capital investment (expensive submarine works)
- Pre-treatment with double pass filtration is highly recommended
- TSS, colloidal matter, TOC, oils and grease are not removed and can produce operational problems
- Potential biological fouling of the intake pipes
- Environmental impact affecting the seabed

3.2.2 Subsurface Intake Systems

3.2.2.1 Vertical Beach Wells

Vertical beach wells basically consist of vertical boreholes near the shoreline. These are typically placed close to the nearshore to capture the sea water which filters through the local nearshore geology. Perforated plastic pipes, which allow water to seep through, are placed in the wells to avoid sand from clogging the well (Wiertz & Gecamin Ltd. 2008).

A beach well is therefore a subterranean reservoir sunk to approximately sea level and coupled to a pipe rammed outward from its bottom into the nearshore geological formation. This pipe has a number of holes to allow the flow of sea water into it. As the water flows into the reservoir, the water fills it up to the same level as the sea. Water can then be pumped from the well to the desalination plant by a multistage, submersible pump. Many wells may be used to provide the required sea water feed capacity for a desalination plant. These wells function under the same filtration rate guidelines as slow sand filters – ensuring low maintenance for proper functioning. The advantages and disadvantages of beach wells are as follows (Wiertz & Gecamin Ltd. 2008; Peters *et al.* 2007; Mackey *et al.* 2011):

Advantages

- Lower capital and O&M costs on the pre-treatment for the desalination plant due to the high and constant quality of the feed water it provides.
- Beach wells completely avoid issues associated with volatile organic spills as well as minimizing the effect of harmful algal blooms
- Overall quality of water supplied by beach wells is excellent
- Since the intake is not physically in contact with the open water, the potential for entrainment and impingement is eliminated. This optimises protection of fish and aquatic life making it attractive from a regulatory standpoint.

Disadvantages

- Limited to smaller desalination plants – a large number of wells needs to be drilled to fulfil the pre-treatments requirements of a typical SWRO plant.
- Hard to identify the most suitable location to drill the wells.
- Expensive geological studies required prior to instalment.
- High numbers of wells are required in order to provide a medium flow rate, requiring a large amount of property to properly space and locate the wells.
- Water supply completely dependent on the hydro geological conditions at the specific site.
- Difficult to predict the evolution of the production flow – it will undoubtedly vary with passing time.
- Very deep wells more than a hundred meters could be required. Production of drilling mud can have adverse environmental impacts and disposal issues.

3.2.2.2 Horizontal Directional-drilled Wells

The horizontal directional drilled well method is comprised of placing a subterranean reservoir much like the vertical beach well in connection with an intake pipe. The reservoir is buried at approximate sea level for the inflow of water from the intake pipe to occur until the water in the reservoir reaches sea level. Bores for the placement of intake pipes are created by means of directional drilling. Directional drilling is typically used for the placement of a single large intake pipe (~750 mm), which serves as a lining for the bore hole. Smaller diameter pipes are placed within this larger pipe and connected to the reservoir. This allows for higher volumes of filtrated sea water from the multiple intakes than can be produced by typical beach wells. The advantages and disadvantages of directional-drilled wells are as follows (Wiertz & Gecamin Ltd. 2008; Peters *et al.* 2007; Mackey *et al.* 2011):

Advantages

- Able to collect very high sea water flows
- TSS, biological suspended matter, debris and hydrocarbons are either greatly reduced or completely eliminated by the system providing a very high quality of water
- Constant water quality
- Construction has little effect on the environment, since most of the drilling is underground
- Simplified pre-treatment for reverse osmosis due to high quality of water
- Can be modified to operate as a deep water intake system if required

Disadvantages

- Studies required prior to instalment (geological continental, marine cartography, and bathymetry)
- Very high capital investment
- Relatively new technique with few references
- Microbiological quality of water is worse than when vertical beach well is used, organic matter can be present in feed water

3.2.3 Targets / Aims of an Intake System

The main aims of an ideal intake system as listed in the presentation by Oscar Alvarado at the Water in Mining July Conference in 2008 (Alvarado 2008) include the following:

- Avoiding suspended organic matter (OM) (solids, colloids, *etcetera*)
- Avoiding dissolved OM (grease, oil, *etcetera*)
- Avoiding biological activity (algae, plankton, *etcetera*)
- Keeping constant physical/chemical characteristics (temperature, salinity *etcetera*)
- Avoiding dissolved heavy metals as well as scaling compounds
- Optimal quality pre-filtered water
- Constant feed flow
- In close proximity to the desalination site to optimize energy consumption
- Flexibility with regards to adjustment of feed flow to meet the needs of the reverse osmosis trains
- Environmentally friendly with as little as possible impact on the surrounding environment and viability to access the beach or coast

These aims should be reached at the lowest cost for a reasonable life span of the intake system. Intake systems can amount to as much as 30% of the capital investment for SWRO desalination plants.

3.2.4 Alternative SWRO Desalination Plant Intake System

Instead of designing and constructing a new surface of subsurface intake, it is sometimes possible to use existing infrastructure. The opportunities are limited, but the options include (Mackey *et al.* 2011):

- **Shared existing intake.** Co-locate, or share an existing intake (typically a power plant intake but in this case an abalone farm intake system).
- **Converted existed intake.** Convert an existing intake line into an intake for the desalination system.

The advantages and disadvantages of using an existing intake system are as follows (Mackey *et al.* 2011):

Advantages

- Potentially large capital savings due to the elimination of infrastructure capital expenses and the O&M costs regarding the intake system.
- From a regulatory standpoint, many of the permits are already in place. Only the modification of an existing permit might be required, saving both time and money.
- Potential water quality benefits depending on the facility sharing the intake system.

Disadvantages

- Permitting can possibly be difficult and costly where public opposition exists to maintaining long-term use of an intake system
- Environmental issues or concerns associated with the existing pipeline would still have to be addressed.
- The water quality at the existing site will have to be accepted regardless of whether an intake at an alternative location would provide advantages in the design and operation of the desalination plant.

The aim of this study is to investigate and determine the feasibility and viability of cost effectively integrating a medium small scale SWRO desalination plant with a typical South African abalone farm, which would imply a shared intake system.

The intake system used by the abalone farm considered for this study is comparable to an open water shoreline intake system. The abalone culture tanks are comparable to simple settling tanks. The only difference between typical settling tanks and the abalone tanks is the components added to the water by what the abalone excrete or secrete as well as the feed supplied to the abalone.

The water coming from the abalone farm might be able to replace the need for a complex intake system which has many benefits with the financial implications being the biggest. However, the water could also possibly be of a lower quality than the water that can be obtained by one of the four mentioned intake systems. The membrane fouling behaviour of the abalone effluent water is unknown. This study aims to investigate the membrane fouling behaviour of the abalone effluent water in order to determine the feasibility and viability of using this water as feed water to an SWRO desalination plant.

Very little is known about water quality dynamics of commercial abalone farms since most companies aim to run their farms as close to the natural environment as possible. They therefore do not change the water quality in any way by adding chemicals. They simply filter the water in various steps and apply temperature control when and where needed.

3.3 FEED WATER CHARACTERISATION

In order to optimally design and adjust pre-treatment and operating parameters for SWRO desalination plants a detailed analysis of the feed water is necessary. Feed water can vary depending on many factors including discharges by local industries, water intake depth, water temperature, algae growth and ocean currents. Although total salt is an important parameter for desalination RO operations, it is not the only important parameter. Biomass, dissolved gasses, concentration of single salts, heavy metals and chemical discharge from industries are all relevant when operating SWRO desalination plants. Water quality can therefore be characterised by means of different key parameters which will be discussed once the different known foulants have been discussed (Fritzmann et al. 2007).

3.3.1 Membrane Foulants

A fundamental knowledge of the possible foulants and how they cause fouling is essential before membrane fouling can be reduced. Fouling behaviour is significantly influenced by various chemical and physical characteristics of the foulants. Foulants can be characterised according to its molecular structure, surface charge, molecular size and functional groups (Zularisam *et al.* 2006). All constituents rejected by the membrane, pose a fouling risk to plant operation. A general classification of membrane fouling includes particle/colloidal fouling, biological fouling, organic fouling, and inorganic fouling (scaling) (Fritzmann *et al.* 2007; Gary 2008). Table 3.3.1 provides a summary of the causes and effects of the different types of membrane foulants identified (Moonkhum *et al.* 2010).

Table 3.3.1 *– Causes and effects of sea water foulants (Moonkhum et al. 2010)*

Foulant	Mechanism	Cause	Effect
Colloidal	Deposition	Accumulation of particles and macromolecules on, in, and near membranes.	Creation of additional resistance layers as to permeation.
OM e.g. polyphenolic compounds, proteins, and polysaccharides)	Adsorption	Permeate resistant layer formation via negatively charged functional groups on organic foulants with charged membrane surface affinity.	Increased cohesion as to membrane surfaces.
		Interaction between organics and micro-organism.	Bio-film formation promotion.
Inorganic (e.g. Iron, silica, aluminium, calcium, phosphorus, and sulphate)	Deposition	Promotion of inorganic matter deposition as to concentration polarization.	Salt precipitation and suspension on membrane surfaces, leading to scaling and fouling.
Biofouling (e.g. bacteria, algae, and fungi)	Adhesion	Micro-organism adhesion and bio-film growth on membrane surfaces.	Bacteria enzymatic biodegradation of membrane material reducing longevity.

3.3.1.1 Concentration Polarisation

Concentration polarisation, inherent to all membrane processes, is the phenomenon that the solute or particle concentration in close proximity to the membrane surface is higher than that in the bulk of the solution filtered (Song & Elimelech 1995). Break-through into the permeate stream is caused by increased concentration of solutes and/or particles at the membrane surface. The risk of fouling is increased and the quality of the permeate as well as the permeation rate (due to increased osmotic pressure) is decreased. Concentration polarisation occurs due to the difference in the permeability between the solvent and the particle/solute. The increased concentration of the solutes and particles at the membrane surface results in a greater back-diffusion into the bulk until a steady state is reached (Shirazi *et al.* 2010). The factors that enhance the back-diffusion reduce concentration polarisation. These factors include an increased cross-flow velocity, a greater diffusion coefficient of the solute/particle, and a higher temperature. In contrast, an increased filtration pressure or permeate flux increases concentration polarisation (Shirazi *et al.* 2010).

3.3.1.2 Inorganic Foulants

Inorganic foulants are known to cause scaling of reverse osmosis membranes. This phenomenon is observed when the concentrations of sparingly soluble salts (i.e. divalent and multivalent ions) exceed their solubility limits. The solubility limit only defines the minimum concentration at which scaling might occur – scaling might not occur even at higher concentrations due to the long induction times of crystallisation. It is however common practice not to exceed solubility limits during operation. The risk of scaling increases with increasing recovery rate (Fritzmann *et al.* 2007).

Dissolved inorganic constituents that are most likely to cause scaling are Ca^{2+}, Mg^{2+}, CO_3^{2-}, SO_4^{2-}, silica and iron. The most likely compounds to be found in scaling on the membrane, when exceeding solubility limits, are the sulphates of calcium, strontium and barium, CaF_2 as well as various silica compounds. The most likely compounds to precipitate before contact with the membrane are the hydroxides of Al, Fe, and Mn. Because most surface and ground waters display high $CaCO_3$ levels close to saturation, the scaling tendency of feed water is typically evaluated using the Langlier Saturation Index (LSI), for brackish water (TDS <10 000 mg/litre), and the Stiff and Davis Stability index (S&DSI), for sea waters (TDS >10 000 mg/litre) (Fritzmann *et al.* 2007). LSI and S&DSI are defined in Appendix A. Precipitation of $CaCO_3$ can be prevented by pH adjustment via acid addition. Carbonate, sulphate and calcium fluoride scaling can also be avoided by the addition of antiscalants. There are many measurement and characterisation techniques for the different types of inorganic fouling and the description of each of them falls outside the scope of this dissertation. The reader is referred to the review paper on inorganic fouling by Shirazi *et al.* (2010) for more details.

3.3.1.3 Particulate Fouling

Particulate matter foulants are classified into four categories according to size (Potts *et al.* 1981):

- settable solids > 100 µm
- supra-colloidal solids 1-100 µm
- colloidal solids 0.001 – 1 µm
- dissolved solids <10 A°

Particles larger than 25 µm are easily removed by various physical treatment options such as screens, cartridge filters, granular-media filters etc. Commonly found inorganic particulate foulants include colloids of iron and aluminium silicate clays. Particles not easily removed by granular media filtration, due to electrostatic forces or minute size, are the most problematic and necessitate the addition of coagulants/flocculants (Fritzmann *et al.* 2007).

An indication of the amount of suspended particles present and their fouling potential can be monitored by the silt density index (SDI). SDI and turbidity are typically required to be NTU <0.2 and SDI <3 – 5 for the prevention of particulate fouling (Fritzmann *et al.* 2007).

3.3.1.4 Biofouling

Micro-organisms, such as bacteria, fungi, algae, viruses and even higher organism such as protozoa – dead or alive – or biotic remains such as cell wall fragments, are present in all raw waters. The concentration of these bio-foulants will be even higher in the abalone effluent water than normal surface water due to the high concentration of animals in the tanks.

The concentration of dissolved organic nutrients at the membrane surface, due to concentration polarization, provides ideal growing conditions for micro-organisms at the surface. Growth of these micro-organisms at the membrane surface, results in the formation of a bio-film (Fritzmann et al. 2007). Bio-film formation consists of three stages (Goosen et al. 2005), namely:

- transport to the membrane surface
- attachment to the surface
- bio-film growth

The bio-film influences RO system performance by increasing the pressure along the feed channel, which results in decreasing flux through the membrane. Biofouling is hard to remove since the organisms are protected from shear force and disinfectants by a gel-like protection layer. Even when the gel layer is removed by disinfectants the remaining dead cellular material can still foul the membranes and furthermore serve as extra nutritional matter, resulting in severe biological re-growth of the remaining living organisms. Significant biofouling can be expected when the bacterial count exceeds 10^6 CFU/ml.

3.3.1.5 Organic foulants

Natural organic matter (NOM) in aquatic systems originates mainly from the degradation of organic matter (i.e. allochthonous) and from the by-products (excretions and secretions) of micro-organism (i.e. autochthonous). NOM can further be characterised into (1) humic, (2) microbial by-products and (3) colloidal NOM (Park *et al.* 2006).

Colloidal NOM can easily be isolated using a dialysis membrane bag with a molecular weight cut off (MWCO) of 3500 Da. This group contains relatively polar amino sugars and typically cause membrane fouling due to its neutrality. In their research Yiantsios and Karabelas

found that, apart from particle size and concentration, colloid stability has a significant effect on RO and UF membrane fouling (Yiantsios & Karabelas, 1998). Key findings included that stable colloidal suspensions caused less fouling and that the use of acid, which is common practice to prevent scaling in desalination, could increase colloidal fouling. Lowering the pH reduces the negative charge on particles; this in turn causes aggregates to form and deposit on the membrane surface.

One major constraint is the organic fouling associated with bulk OM. The classification of organic fouling overlaps those of colloidal fouling and biological fouling. Organic foulants can include macromolecules as well as organic colloids. It becomes even more difficult to classify foulants since biological fouling can be considered to be the biotic form of organic fouling whereas organic matter derived from microbiological cellular debris can be considered as an abiotic form of biological fouling (Gary 2008).

Three types of organic matter are of interest in waste water reclamation or re-use and drinking water treatment.

1. **Allochthonous NOM.** Allochthonous NOM mainly originates from the degradation of organics and is dominated by humic substances derived from runoff and leaching of vegetative debris from terrestrial sources within the watershed or aquatic system (Park et al. 2006; Gary 2008).
2. **Autochthonous or algal NOM.** Autochthonous NOM consists of the by-products of micro-organisms, that is, extracellular an intracellular macromolecules and cellular debris (Park et al. 2006; Gary 2008).
3. **Wastewater effluent organic matter (EfOM).** Wastewater effluent consists of background NOM as well as soluble microbial products (SMP) derived from biological wastewater treatment.

In this study wastewater effluent is not really of concern and the focus will therefore be on NOM and its components as the major membrane foulants that occur during the water filtration process. NOM is one of the most important identified foulants in surface water filtration. In water NOM is a complex heterogeneous mixture of particulate and soluble components with wide ranges in molecular weight (MW) and functional groups (phenolic, hydroxyl, carbonyl groups and carboxylic acid) originating from the two sources mentioned. Amongst all these components the dissolved organic matter (DOM) fraction is found to have the most detrimental effect on membrane performance as it can result in irreversible fouling of the membrane during surface water filtration (Zularisam *et al.* 2006).

DOM is found everywhere in natural waters and generally is comprised of humic substances, polysaccharides, amino acids, proteins, fatty acids, phenols, carboxylic acids, quinines, lignin, carbohydrates, alcohols, resins and inorganic compounds such as silica, alumina-silicates, iron, aluminium, suspended solids and micro-organisms (bacteria and fungus) (Zularisam *et al.* 2006).

NOM can on the other hand be fractionated into three sections based on its behaviour in water: hydrophobic (humic substances), hydrophilic and transphilic fractions. The fractions represented in Figure 3. 3.1.5 are based on dissolved organic carbon (DOC) measurements.

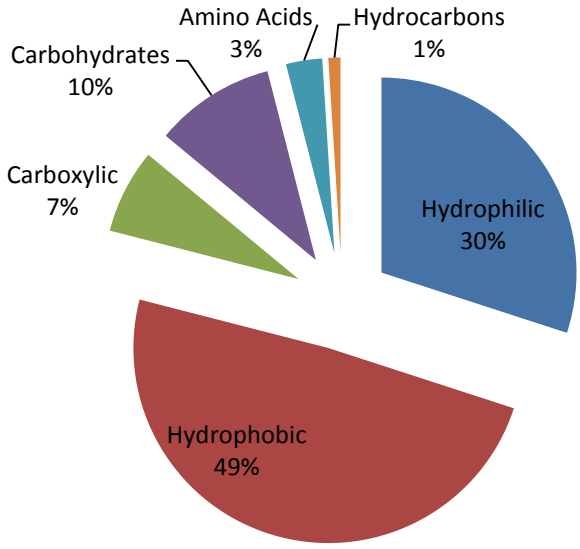

Figure 3.3.1.5.1 *– Fraction of NOM in surface sea water based on DOC (Zularisam et al. 2006)*

The hydrophobic (humic substances) fraction represents almost 50% of the DOC. The hydrophilic fraction represents between 25% – 40% of the DOC with lower MW (polysaccharides, amino acids, protein etc.) and can operationally be defined as being the non-humic fraction. The transphilic fraction is comprised of approximately 25% DOC in natural water but with MW in between those of the hydrophobic and hydrophilic fractions (Zularisam *et al.* 2006).

The hydrophobic fraction consists mainly of humic substances. Humic substances in general terms are the products of the decomposition of primarily plant material by microbes. Humic substances are subdivided into three categories: humin, the fraction of humic substances that is insoluble in water at all pH values; humic acid (HA), the fraction of humic substances that is insoluble in water at all pH 2 but becomes soluble at higher pH; and fulvic acid (FA), the fraction that is soluble under all pH conditions (Drever 1997).

Humic substances in natural waters are usually between the concentrations of 0.5 – 20 mg/litre in brackish water and up to 100mg/litre in sea water. These values are expected to be higher for the abalone farm effluent due to the high concentration of organic material present in the tanks. Humic acids have a polymeric phenolic structure, forms chelates with metal ions (mostly iron ions) and a gel-like fouling layer by the complexation of multivalent ions. These organics cause a decline in permeability when adsorbed unto the membrane surface. In some cases they even cause irreversible fouling, mostly due to complexation of calcium, since calcium complexes form a more highly compacted floc structure causing larger flux decline in comparison to the other chelates. It is recommended that humic substances are removed prior to filter-pre-treatment by means of flocculation/coagulation, ultrafiltration, adsorption or activated carbon (Goosen *et al.* 2005; Fritzmann *et al.* 2007).

The hydrophilic fraction consisting mostly of microbial by-products is composed of high charge density acids, amino sugars, and polysaccharide. In a study of the characterization of colloidal and microbial organic matters with respect to membrane foulants (Park et al. 2006), it is revealed that colloidal NOM, including microbial by-products such as polysaccharides, amino sugars and proteins cause severe flux decline and fouling propensities during nanofiltration.

When proteins reach the membrane surface, they adsorb to the membrane which can cause a cascading reaction of more proteins adsorbing. There is a value for a protein called adiabatic compressibility which is a measure of how compressible a protein is. To shed light on this characteristic one can think of proteins as long string-like molecules that are wound with different densities. A high adiabatic compressibility will then indicate a very loosely wound protein and a low compressibility will indicate a tightly wound protein. Proteins with high adiabatic compressibility are very "soft" and can unfold on the surface, magnifying the fouling (adsorption). When this happens, the protein film (layers of protein fouling) is very difficult to remove.

A dual-mode fouling process, similar to that observed for humic acids, was found for protein [(i.e., bovine serum albumin (BSA)] fouling of micro- filtration (MF) membranes. First protein aggregates form on the membrane surface, followed by native (i.e. non-aggregated) proteins. The native proteins attach to the existing proteins by means of intermolecular disulfide linkages formed between them. The researchers that observed this dual-mode fouling phenomenon also successfully developed a mathematical model to describe the process (Schäfer *et al.* 2002)

Gary also addresses important issues regarding the nature of NOM fouling in her paper on the fundamentals of NOM membrane fouling (Gary 2008). The simplest measure of the total

concentration of organic solutes is the concentration of DOC, which is measured by converting all the OM in solution to CO_2 and then measuring the CO_2 produced. Now various methods exist for both the first (conversion to CO_2) and second (measuring CO_2) step in determining the DOC concentration. OM is considered dissolved if it passes through a 0.45 µm filter, and it is particulate if it is retained by the filter. The term TOC is the organic carbon content of the unfiltered sample. Figure 3.3.1.5.2 illustrates the classification of carbon in sea water samples.

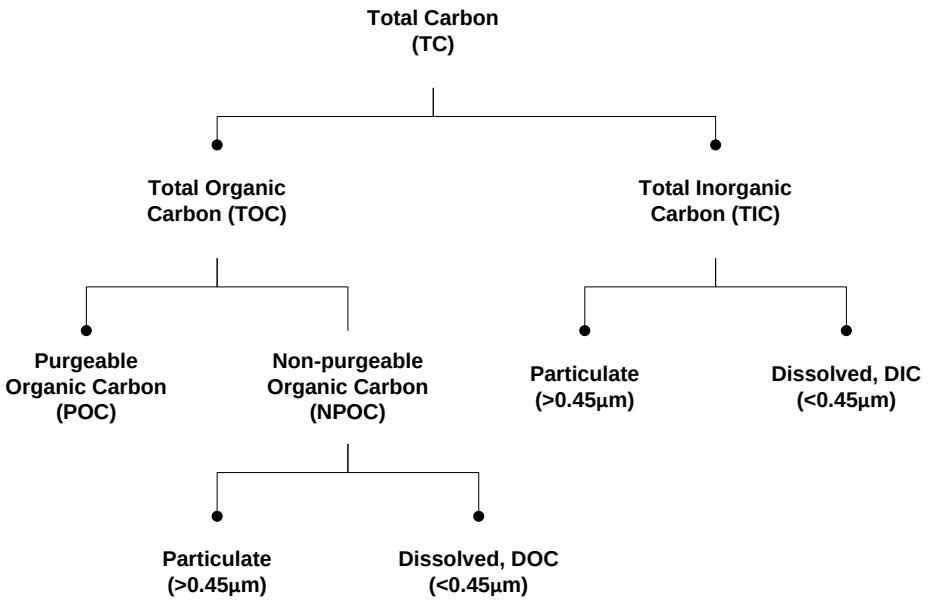

Figure 3.3.1.5.2 *- Classification of carbon in sea water samples*

There is a number of other routine and novel OM measurement and characterisation protocols that can be applied to characterise bulk samples of feed water (refer to Appendix A for an elaboration on these techniques as taken from papers by Zularisam *et al.* (Zularisam *et al.* 2006) and Gary (Gary 2008)*)*. DOC is used throughout this study as a measure of the organic matter present in the water.

3.3.1.6 Transparent Exopolymer Particles

It has recently been proposed that transparent exopolymer particles (TEP) play an important role in the start and development of aquatic biofilm (Berman *et al.* 2011; Kennedy *et al.* 2009; Villacorte *et al.* 2009). TEP are sticky organic micro-gels, everywhere in natural waters, which provide a nutritious organic substrate for the colonisation of bacteria and other micro-organisms. Many substances are associated with these gel-like particles, including polysaccharides, nucleic acids, proteins and trace elements (Mari & Kiørboe 1996; Berman & Parparova, 2010; Berman 2010; Berman *et al.* 2011).

3.3.2 Fouling Prediction Indices

Cleaning frequency, pre-treatment requirements, operating conditions, cost and system performances are all affected by membrane fouling. Estimating the fouling potential of RO feed water is therefore a prerequisite to control membrane fouling successfully and to evaluate the effectiveness of the applied pre-treatment. For this purpose two different tests are mostly used in this field, i.e. the Silt Density Index (SDI) and the Modified Fouling Index ($MFI/MFI_{0.45}$). In both tests microfiltration membranes with pores of 0.45µm are used and the rate of flux decline at constant pressure is measured. In principle these tests can be done using the same equipment (Hong *et al.* 2009; Alhadidi *et al.* 2011).

3.3.2.1 Silt Density Index

The silt density index (SDI) is an empirical test initially developed by Dupont Permasep to characterise the fouling potential of their hollow fibre elements in 1987 (Alhadidi et al. 2011). The SDI is a parameter characterising the fouling potential of water. It is one of the most important parameters used for the design and operation of RO membrane processes. SDI analytical protocol is standardised in the ASTM D4189-07 document (ASTM 2007). In SDI tests, membranes with pores of 0.45 µm are used to measure the rate of flux decline at constant pressure. The SDI test has been applied worldwide for many years because it is cheap and simple and, hence, executed on a routine basis by operators. Details on the equipment, method and deficiencies of the SDI can be found in Appendix A.

3.3.2.2 Modified Fouling Index

To overcome the SDI deficiencies the modified fouling index (MFI) was developed. The subscript 0.45 indicates that a 0.45 µm membrane is used in the test. This test is based on the occurrence of cake filtration during a substantial part of the test, has a linear relation with particulate matter content, and is corrected for pressure and temperature. However the manual procedure of measuring an $MFI_{0.45}$ is more complicated and for this reason less suitable for routine application in practice by the operators (Alhadidi *et al.* 2011).

The $MFI_{0.45}$ was derived by Schippers and Verdouw in 1980 from the SDI (Schippers & Verdouw ,1980) by assuming a cake filtration mechanism. It aimed at measuring the fouling potential of feed water for reverse osmosis installations. To determine the $MFI_{0.45}$, the flow through the filter is measured as a function of time. These data are processed with equation 3.3.2.2a which follows from the theory of cake filtration (Alhadidi *et al.* 2011) :

$$\frac{t}{V} = \frac{\mu \cdot R_M}{dP \cdot A_M} + \frac{\mu \cdot I}{2 \cdot \Delta P \cdot A_M^2} \cdot V \qquad \textit{equation 3.3.2.2a}$$

where

t	time (s)
V	accumulated filtrate volume (m^3)
μ	water viscosity (Pa.s)
R_M	clean membrane resistance (m^{-1})
dP	applied pressure (Pa)
A_M	membrane surface area (m^2)
I	fouling potential index (m^{-2})

The $MFI_{0.45}$ is derived from the slope in the relationship of t/V versus V, as given in equation 3.3.2.2b:

$$tg\alpha = \frac{\mu \cdot I}{2 \cdot \Delta P \cdot A_M^2} \qquad \textit{equation 3.3.2.2b}$$

This slope *tgα* is by definition equal to $MFI_{0.45}$ when it has its minimum value and under the conditions that the temperature is 20°C, the pressure is 207 kPa and the membrane surface area equals 1.38×10^{-3} m^2 (0.047 m diameter). The $MFI_{0.45}$ is corrected for T and P using equation 3.3.2.2c and is therefore independent of temperature and pressure:

$$MFI_{0.45} = tg\alpha \times \frac{\mu}{\mu_{20}} \times \frac{dP}{dP_0} \times \left(\frac{A_M}{A_{M0}}\right)^2 \qquad \textit{equation 3.3.2.2c}$$

where

μ_{20}	water viscosity at 20°C (Pa.s)
A_{M0}	reference membrane surface area (1.38×10^{-3} m^2)
dP_0	reference applied pressure (2.07×10^5 Pa)

The water viscosity at temperature T (°C) can be calculated using the following empirical equation 3.3.2.2d (Greenlee *et al.* 2009) or for more accurate results, specifically for sea water on databases such as the one provided by MIT on their website (MIT 2011). A review of existing correlations and data on the thermo physical properties of sea water done by Sharqawy *et al.* (2010) can also be useful.

$$\mu = 0.479 \times (T + 42.5)^{-1.5} \qquad \textit{equation 3.3.2.2d}$$

The minimum value of tgα is by definition $MFI_{0.45}$, since at the start of filtration the filtration mechanism is frequently pore blocking resulting in a high slope. Subsequently cake filtration starts and becomes gradually the governing mechanism until cake compression starts, resulting in an increasing slope. See Figure 3.3.2.2 below:

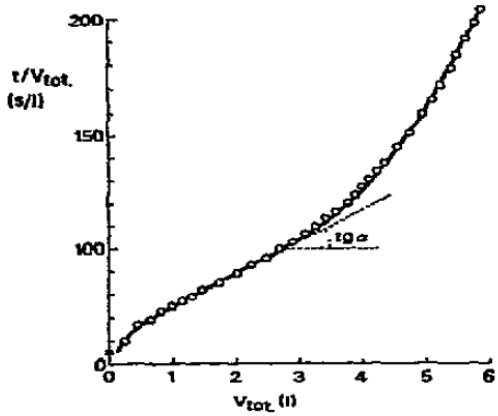

Figure 3.3.2.2 *- Ratio of filtration time and filtrate volume (V) as a function of total filtrate volume (J.C. Schippers & Verdouw, 1980).*

The $MFI_{0.45}$ is expressed in s/litre^2 to get values which are in the same order of magnitude as SDI. The recommended MFI values for acceptable operations are 0 – 2 s/litre^2 for RO and 0 – 10 s/litre^2 for nanofiltration (Schippers & Verdouw, 1980).

3.3.2.3 Alternative Fouling Indices

Since the 0.45 µm MF membrane used for SDI and $MFI_{0.45}$ determinations is unable to capture particles smaller than 0.45 µm, new fouling indices were developed based on the MFI definition using membranes with smaller pore sizes (MFI_{UF}, MFI_{NF}), different filtration systems (MFI_{UF} constant pressure, MFI_{UF} constant flux) and different hydraulic systems (dead-end MFI, cross-flow sampler CFS-MFI_{UF}) (Alhadidi *et al.* 2011).

The approach for MFI_{UF} and MFI_{NF} is the same as for the $MFI_{0.45}$ tests to determine values of the fouling resistance of the cake layer formed on the membrane. The only difference is that ultrafiltration membranes are used in the tests instead of the 0.45 µm microfiltration filters for more accurate colloidal fouling prediction by retaining smaller particles (Fritzmann *et al.* 2007; Alhadidi *et al.* 2011). Running times for the MFI_{UF} test are much longer (1 – 5 hours) and MFI_{UF} is defined similarly to the MFI as shown by equation 3.3.2.3.

$$MF_{UF} = tg\alpha \times \frac{\mu}{\mu_{20}} \times \frac{dP}{dP_0} \times \left(\frac{A_M}{A_{M0}}\right)^2 \qquad \textit{equation 3.3.2.3}$$

3.4 REVERSE OSMOSIS PRE-TREATMENT

The primary goal of any RO feed water pre-treatment system is to minimize the fouling propensity of the water in the RO system (Greenlee *et al.* 2009).

Typically the pre-treatment can be divided into four steps:

1. removing suspended solids (SS)
2. preventing bio-growth
3. preventing scaling
4. preventing organic adhesion

The conventional pre-treatment process as well as the more recently developed membrane pre-treatment processes will be discussed here.

3.4.1 Chemical Pre-treatment

Chemical pre-treatment includes the addition of any chemicals upstream of the reverse osmosis stage. The type of pre-treatment applied significantly influences the amount of chemicals used, conventional pre-treatment tends to use more chemicals than membrane pre-treatment.

3.4.1.1 Chlorination/Biocide (DBNPA)

Several methods for controlling biofouling exist and are discussed in detail by Al-Juboori and Yusaf in their paper on the mechanisms, monitoring and controlling of biofouling in RO systems (Al-Juboori & Yusaf n.d.). The most common techniques are chemical techniques such as chlorination or the addition of 2,2-Dibromo-3-nitrilopropionamide (DBNPA) and are therefore the techniques employed during this study.

Chlorination is required, independent of the type of pre-treatment applied, to disinfect the water and thereby prevent biological growth which can cause biofouling. Chlorine is typically added as sodium hypochlorite (NaOCl) or as chlorine gas (Cl_2), which hydrolyses to form hypochlorous acid in the water. The hypochlorous acid then dissociates to form hydrogen and hypochlorite ions (Fritzmann *et al.* 2007) - refer to Appendix A, equation A4.1 for this reaction. The sum total of Cl_2, NaOCl, HOCl and OCl^- is referred to as the free residual chlorine; this value is typically maintained at 0.5 to 1.0 mg/litre along the pre-treatment line for the prevention of biofouling (Fritzmann *et al.* 2007).

The application of DBNPA as biofouling control for RO systems has gained popularity due to its compatibility with RO membranes typically sensitive to free chlorine. DBNPA is a highly

effective, non-oxidising and more environmentally friendly biocide. It provides a quick kill while also quickly degrading in water. The final end product is carbon dioxide and ammonium bromide. There are two different dosing types: slug dosing and continuous feed dosing. With slug dosing, dosing rate depends on the severity of the biological fouling. With water less prone to biological fouling, using 50 – 170 mg/litre of the 20% active ingredients product for 30 minutes to 3 hours, every 5 days should be enough. If the feed water contains >102 CFU/ml or you knowingly have biofilm within the RO system, 170 mg/litre for 3 hours is recommended. Once the system is void of significant biofilm, a continuous feed maintenance programme can be instituted; 10 to 15 mg/litre of the product would be the recommended dosage (DOW 2012).

For further details on the use of Chlorine and DBNPA the reader is referred to the *DOW FILMTEC Elements Technical Manual Section 2.6*, available on the DOW website (DOW 2012)

3.4.1.2 Coagulation and Flocculation

All waters contain both suspended and dissolved particles. Coagulation and flocculation processes are used to separate the suspended particles from the water. It is therefore applied to prevent particulate fouling as described earlier.

The suspended particles vary considerably in composition, charge, particle size, density and source. The correct application of coagulation and flocculation processes and the correct selection of coagulants depend on understanding the interaction between these factors for the particles present in the water to be treated. The concentration of these compounds in water is described by using sum parameters. Four sum parameters typically used to describe surface waters are as follows (Droste 1997):

- SS concentration (dry weight)
- turbidity
- NOM (expressed in TOC/DOC)
- colour

The suspended solids concentration and turbidity are caused by colloidal particles (order of magnitude 0.1 – 10 µm). Colloidal particles are negatively charged and repulse each other. Colour is caused by humic substances (order of magnitude 0.01 µm). The charge of humic substances (and thus the removal thereof) is highly dependent on the pH of the water.

Coagulation and flocculation occur in successive steps intended to overcome the forces stabilising the suspended particles, allowing particle collision and growth of floc. If step one is incomplete, the following step will be unsuccessful.

In the first step the particle's charges are destabilised. Coagulants with charges opposite those of the suspended particles are added to the water to neutralise the negative charges on dispersed non-settable solids.

The small suspended particles are capable of sticking together since the charge is neutralised. The slightly larger particles, formed through this process and called micro-flocs, cannot be seen with the naked eye. The water surrounding the newly formed micro-flocs should be clear since it should no longer contain dispersed non-settable solids. Unclear water is an indication that all the particles' charges have not been neutralized and coagulation has not been carried to completion. An increased coagulant dosage is then required.

A high-energy, rapid mix to properly disperse the coagulant and promote particle collisions is needed to achieve good coagulation. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete. Coagulants should be added where sufficient mixing will occur and is typically added in-line when used for UF/MF processes (Johir *et al.* 2009; Droste 1997). Rapid mixing after coagulant dosing is an important design parameter. The coagulant must be uniformly mixed with the raw water. In case mixing is poor, local under- and overdosing occurs, resulting in poor performance of the process. The parameter used to express mixing intensity is called the velocity gradient or G-value and is defined as follows, equation 3.4.1.2a:

$$G = \sqrt{\frac{P}{\mu \cdot V}} \qquad \textit{equation 3.4.1.2a}$$

where,

- G velocity gradient for rapid mixing (s^{-1})
- P dissipated power (W)
- μ dynamic water viscosity ($N \cdot s/m^2$)
- V volume of mixing tank (m^3)

The influence of the velocity gradient can easily be determined by jar-test experiments. When the velocity gradient is low (less intensive mixing) the residual turbidity will be higher than in situations where the velocity gradient is high (more intensive mixing). In practice, the recommended G-value for rapid mixing is 1500 s^{-1}, at a minimum.

Two different mixing systems can be applied namely mechanical mixing or static mixing. In the first system mechanical mixers dissipate the power in the raw water, whereas in the second system gravity forces cause the mixing effect. Here, the dissipated power is a consequence of the head loss over the mixing tank, equation 3.4.1.2b.

$$\boldsymbol{P = \rho \cdot g \cdot Q \cdot \Delta H} \qquad \textit{equation 3.4.1.2b}$$

where,

ρ density of water (kg/m^3)
g gravity constant (m/s^2)
Q flow (m^3/s)
ΔH head loss over mixing tank (m)

The equation for the velocity gradient for static mixers can be written as, equation 3.4.1.2c:

$$\boldsymbol{G = \sqrt{\frac{\rho \cdot g \cdot Q \cdot \Delta H}{\mu \cdot \tau}}} \qquad \textit{equation 3.4.1.2c}$$

where,

τ residence time in the mixing zone (s)

The most frequently applied static mixer is the cascade where the water falls over a weir and into a receiving body. In the turbulent space that is caused by the falling water, coagulant is dosed. The second step called flocculation follows the first step of coagulation. Flocculation increases the particle size from microscopic micro-floc to visible suspended particles.

Slow mixing brings the microflocs into contact with each other. Colliding microflocs bond to produce larger, visible flocs called pin-flocs. The flocs continue to grow through additional collisions and interaction with inorganic polymers formed by the coagulant or with organic polymers added. Macro-flocs are formed. High molecular weight polymers, called coagulant aids, may be added during this step to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once the floc has reached its optimum size and strength, the water is ready for the sedimentation process. Subsequent sedimentation, granular media filtration, cartridge filtration or membrane filtration is then applied to remove these agglomerates from the water. This is the third and final step.

The choice of coagulant chemical depends on the nature of the suspended solid to be removed, the raw water conditions, the facility design, and the cost of the amount of chemicals necessary to produce the desired result. The coagulant most frequently used for

desalination plants is iron(III)chloride ($FeCl_3$) (Fritzmann *et al.* 2007). This is also the coagulant used throughout this study. A summary of the different types of coagulants as well as their reactions and coagulation mechanism are discussed in more detail in Appendix A.

Jeong *et al.* (2011) proved in their study on the performance of iron(III)chloride as flocculent that the highest DOC removals, 57%, were obtained at a concentration of 3 mg/litre as Fe^{3+}. At lower doses, the DOC removal efficiencies were below 50% and at higher doses the DOC removal efficiency started to decrease due to re-stabilisation of the colloidal particles. The pH, salinity, total suspended solids (TSS) and turbidity sea water used in their study were 8, 35 500 – 40 000 mg/litre, 2 – 13 mg/litre and 0.41 – 1.7 NTU. The DOC was 1.29 – 1.45 mg/litre. The water used in their study was very similar to the feed water of the SWRO desalination pilot plant in this study. Flocculation is therefore carried out at 3 mg/litre (as Fe^{3+}) during the pilot study.

3.4.1.3 pH Adjustment

The pH is generally shifted to lower values, pH 4 – 6, in RO applications where the RO membranes perform better. Sulphuric acid is typically used to achieve the desired pH value. The pH adjustments further serve to prevent scaling of $CaCO_3$ (Fritzmann *et al.* 2007). A stable pH at the optimum pH for coagulation and flocculation will ensure stable coagulation and flocculation behaviour which is important for pre-treatment purposes.

3.4.1.4 Antiscaling Agents

Antiscalants are typically dosed after granular media or membrane filtration (either before or after cartridge filtration). Antiscalant prevents saturated salts from precipitating and forms a highly supersaturated, metastable solution. Antiscalants are surface active materials and three primary ways in which they interfere with precipitation reactions have been identified as threshold inhibition, crystal modification or dispersion and are explained in more detail in Appendix A. The membrane manufacture, DOW, recommends an antiscalant dosing rate that gives a concentration of 20 mg/litre in the concentrate stream (DOW 2012).

3.4.1.5 Dechlorination

Residual chlorine in the RO element may damage the membrane by means of oxidation and should therefore be removed prior to the RO stage. Chlorine resistance depends on the type of membrane used but typical degradation of membranes happens after exposure of 200 – 1000 hours at 1 mg/litre free chlorine for composite membranes. The rate of degradation is also affected by pH and temperature – degradation is higher in alkaline water and at higher temperatures (Fritzmann *et al.* 2007).

Sodium metabisulphite (SMBS) is typically used for de-chlorination due to its high cost-effectiveness. In practice 3 mg/litre of SMBS is used per 1 mg/litre of free chlorine for dechlorination instead of the theoretically required 1.34 SMBS per 1 mg/litre chlorine (Fritzmann *et al.* 2007). Activated carbon can also be applied to effectively remove residual free chlorine. Refer to Appendix A for the dechlorination reactions. Finally it is important that the dechlorination dosing point in the pre-treatment train has a significant influence on membrane performance.

3.4.2 Conventional Pre-treatment

Conventional pre-treatment usually consists of the following steps:

1. screens for coarse pre-filtration
2. chlorination
3. acid addition
4. coagulation
5. flocculants
6. single- or double-stage granular media filtration
7. sodium bisulphite addition and antiscalant
8. cartridge filtration

The first chemical additions include acid addition and coagulant/flocculant addition; this prepares the feed water for the granular media filtration step. The pH is typically reduced to a range between pH 5 – 7 by the acid treatment, increasing the solubility of calcium carbonate ($CaCO_3$) which is a key potential precipitate in many feed waters. Aqueous suspended particulate and colloidal matter are typically negatively charged and repel one another due to these similar charges. Coagulants effectively neutralise similar charges between the suspended solids to allow them to group together in flocs (large groups of loosely bound suspended particles). Coagulants are therefore typically small positively charged molecules (Greenlee *et al.* 2009).

Granular media filtration includes materials such as sand, anthracite, pumice, gravel, and garnet. Combinations of these materials are typically used in layers in the filtration bed in order to take advantage of the materials' different effective sizes and properties. Filtration can either be carried out at atmospheric pressure (open) or under higher pressures (closed). The pressurised filtration method (although more energy intensive and expensive) is more commonly used in the RO pre-treatment process. SDI can typically be reduced by a factor of two via this process. Media filtration permeate turbidity is around 0.1 NTU for the pressurised process. Granular media filtration is sensitive to feed water changes, such as algal blooms or oils spills, resulting in the SDI varying several units. Oil contamination, which is a

particularly difficult problem, can be removed by dissolved air flotation (DAF) during membrane pre-treatment (Greenlee *et al.* 2009).

The last step in conventional RO pre-treatment is cartridge filtration. Filter cartridges are typically 1 – 10 µm and serve as a final cleaning step to remove the particles that have passed through the granular media filtration bed. Particulate matter larger than 5 – 10 µm will foul RO membranes; filter cartridges are therefore a necessary step before RO treatment.

Antiscalants are typically dosed after granular media filtration (either before or after cartridge filtration). Antiscalant, as mentioned, prevents saturated salts from precipitating and forms a highly supersaturated, metastable solution.

Disinfection is achieved by the addition of strong oxidants such as ozone, chlorine (gas, chlorine dioxide, or sodium hypochlorite), chloramines, or potassium permanganate. The oxidants are dosed at a high enough level to allow residual disinfectant throughout the rest of the pre-treatment system to prevent biological growth. Whenever chlorine is used as disinfectant, activated carbon or sodium bisulphite is used at the end of the process to chemically reduce the chlorine since the majority of RO membranes are known to be sensitive to chemical attack by chlorine (Greenlee *et al.* 2009). Figure 3.4.2 shows a very simple process flow diagram of an SWRO desalination plant with media filtration as pre-treatment (after primary screens).

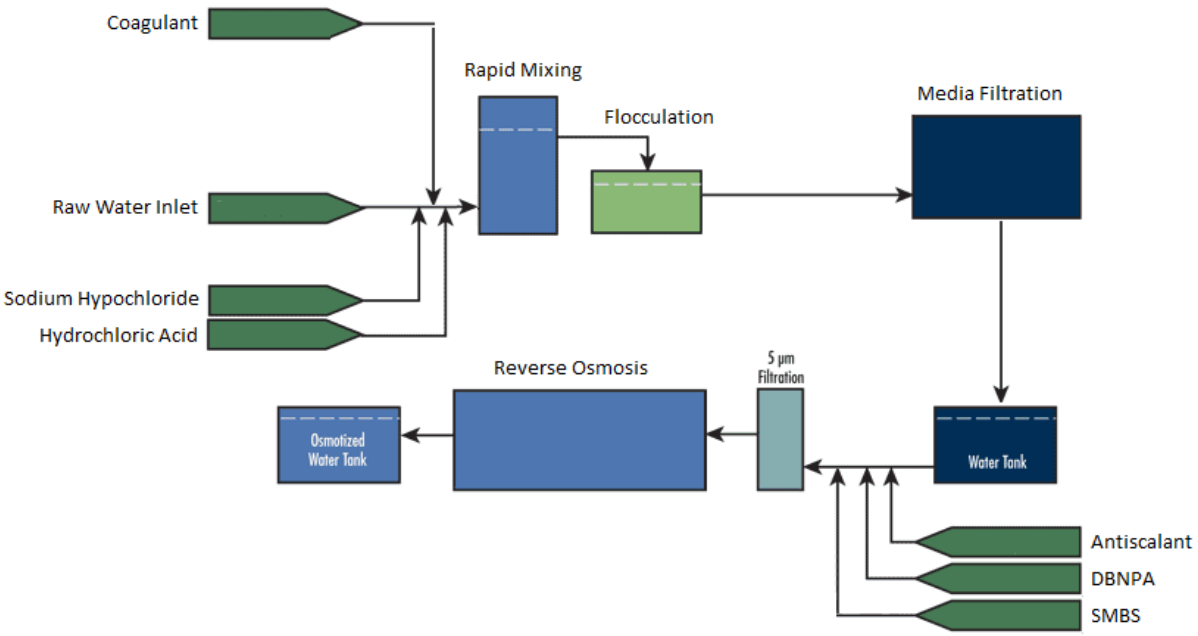

Figure 3.4.2 *– SWRO desalination plant process flow diagram with media filtration pre-treatment*

3.4.3 Membrane Pre-treatment

It has been mentioned that variations in feed water quality can cause variation in conventional RO pre-treatment effectiveness leading to colloids and suspended particles passing through to the RO membranes causing difficult to remove and often irreversible fouling (Greenlee *et al.* 2009).

MF and UF are filtration processes that operate on a physical sieving separation process. When conventional pre-treatment filtration is not sufficient, the use of a MF or UF system is a solution to remove turbidity, viruses and bacteria from a feed water source. MF/UF provides excellent pre-treatment for SWRO and high turbidity brackish reverse osmosis (BWRO) systems. MF/UF systems can directly produce potable water with 4 log virus removal and less than 0.10 NTU of turbidity. MF membranes will render larger permeate production rates with lower contaminant removal and are therefore the appropriate choice for the removal of larger particulate matter at higher permeate fluxes (Greenlee *et al.* 2009).

NF is similar to reverse osmosis – the key difference being the degree of removal of monovalent ions such as chlorides by the nano-filtration and reverse osmosis membranes. The filtration process takes place on a selective separation layer formed by an organic semi-permeable membrane. NF membranes will give lower permeate production rates with higher contaminant removal efficiencies and are used to remove dissolved contaminants as well as particulate and colloidal material (Greenlee *et al.* 2009).

The use of larger pore sized membranes (MF, UF, NF) has recently become more popular than the conventional methods for the pre-treatment of RO feed water. Various UF membranes seem to be the most popular in pilot testing and research studies since they present the best balance between permeate production rate and contaminant removal of all three the membranes (Greenlee *et al.* 2009). If required, these membranes can be applied in combination with each other. All three membranes have advantageous characteristics and each treatment plant should choose the pre-treatment to be used based on specific feed water contaminant levels (Greenlee *et al.* 2009).

Membrane pre-treatment provides several advantages in comparison to conventional multi-media filtration as pre-treatment to RO. Membranes act as a definite barrier between the RO system and any suspended particles. SDI can be lowered to less than 2 and turbidity typically to less than 0.05 NTU. It is particularly advantageous to RO systems treating surface water (such as sea water open intakes and brackish surface water) since these water sources tend to contain more organic colloidal and suspended matter than underground water. These water sources are also subject to higher variability and sporadic problematic events such as algal blooms which are better handled by membrane pre-

treatment than the conventional methods. Membrane pre-treatment furthermore significantly increases the expected operational lifetime of RO membranes. RO replacements as well as the amount of chemical cleaning treatment are reduced (Greenlee *et al.* 2009).

Membrane pre-treatment also has its disadvantages. The main disadvantage is the membranes' inherent propensity to become fouled in removing foulants from the product water. Surface and pore fouling occur for all three membrane types used (MF, UF, NF), this prevents operation at high permeate flux as fouling causes membrane damage and a decline in flux (Greenlee *et al.* 2009).

Hydrocarbons (oils) and cellular or extracellular material (from bacteria) have been shown to be particularly successful foulants (Brehant *et al.* 2002). This can become a problem when working with the effluent from the abalone farms where the number of organic organisms within the abalone tanks may be higher than that for raw sea water due to the high concentration of animals. The suspended solids on the other hand should be lower than that of raw sea water. NF membranes, as RO membranes, can also be subjected to salt precipitation due to its smaller pore size. UF and MF membranes are known to be replaced every 5 to 10 years (Greenlee *et al.* 2009)

Coagulation can successfully be used in-line with MF, UF and NF pre-treatments systems and prevents fouling during the treatment of RO feed water. It is however very sensitive to the dosage used and if a too high or low dosage is used it can lead to permeate flux decline. Also, coagulant cannot be used together with antiscalants since antiscalants are typically negatively charged and will form a fouling complex (difficult to remove) when combined with the positively charged coagulant. Antiscalants are therefore dosed between the pre-treatment membranes and the RO unit, while coagulants are dosed prior to the membrane pre-treatment.

Table 3.4.3, adapted from the paper by Younos & Tulou (2009), gives an overview of desalination techniques and summarises the pressure-driven membrane processes in terms of the required pressure, minimum size retained and typical applications.

Table 3.4.3 *– Overview of pressure-driven membrane-based desalination technologies*

Membrane Process	Pressure (kPa)	Particles Retained	Application (type, removal efficiency)
Microfiltration	30 – 500	0.1 – 3 µm	(1) Particle/turbidity removal (>99%) (2) Bacteria/protozoa removal (>99.99%)
Ultrafiltration	30 – 500	0.01 – 0.1 µm	(1) Particle/turbidity removal (99%) (2) Bacteria/protozoa removal (99.99%) (3) TOC removal (<20%) (4) Virus removal (partial credit only)
Nanofiltration	500 – 1000	200 – 400 Da	(1) Turbidity removal (>99%) (2) Colour removal (>99%) (3) TOC removal (DBP control) (>95%) (4) Hardness removal (softening) (>90%) (5) Synthetic organic contaminant (SOC) removal (500+ Daltons) (100%) (6) Sulphate removal (>97%) (7) Virus removal (>95%)
Hyperfiltration (RO)	1000 – 5000	50 – 200 Da	(1) Salinity removal (>99%) (2) Colour and DOC removal (>97%) (3) Radionuclide removal (excluding radon) (>97%) (4) Nitrate removal (85 - 95%) (5) Pesticide/SOC removal (0 - 100%) (6) Virus removal (>95%) (7) As, Cd, Cr, Pb. F removal (40 to > 98%)

Capital cost for membrane pre-treatment systems are decreasing and are rapidly becoming cost-competitive with conventional pre-treatment methods. Refer to Appendix A for illustrations which show the typical removal rates for the different thin-film composite membranes (MF, UF, NF). Figure 3.4.3 presents a process flow diagram of an SWRO desalination plant with ultrafiltration as pre-treatment (after primary screens).

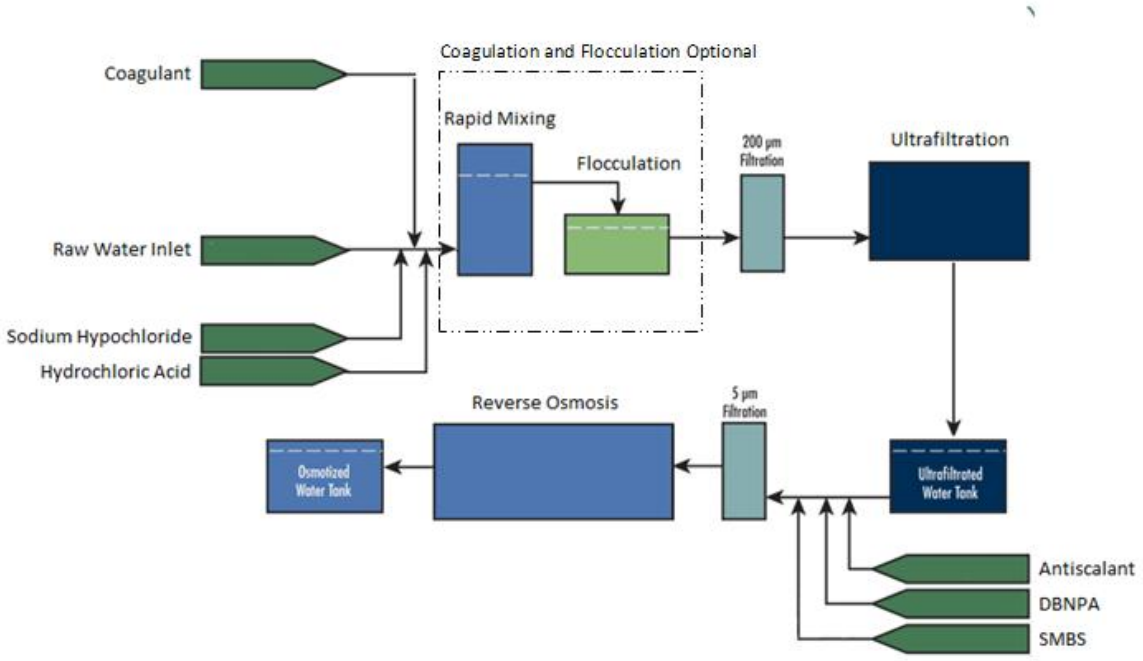

Figure 3.4.3 *– SWRO desalination process flow diagram with ultrafiltration pre-treatment*

3.5 REVERSE OSMOSIS

The most commonly used desalination technologies today are reverse osmosis and thermal desalination methods such as multi-stage flash and multi-effect distillation. However, reverse osmosis has, due to its lower energy consumption, gained much wider acceptance than its thermal counterparts all over the world.

Now that desalination in its broader sense, as well as abalone farming in South Africa has been discussed, the focus is turned towards this specific desalination method that will be applied throughout this research project.

3.5.1 Basic Terms and Definitions

The basic terms used in describing reverse osmosis systems can be found in the glossary of this document. The calculation of most of these important parameters is shown in this section.

3.5.1.1 Osmotic and Operating Pressure

The osmotic pressure (π) of a solution is a function of the amount of dissolved salts in the solution and can be experimentally measured. Osmotic pressure is obtained by equation 3.5.1.1 (El-Dessouky & Ettouney 2002).

$$\boldsymbol{\pi = RT \sum C_i} \qquad \textit{equation 3.5.1.1}$$

where,

π	osmotic pressure (Pa)
R	universal gas constant (Pa.m^3/mol.K)
T	temperature (K)
C_i	concentration of constituent i in the water (mol/m^3)

In the case of common saline brackish water or sea water, one can estimate the osmotic pressure by assuming that 1000mg/litre of TDS is equal to 75.84kPa of osmotic pressure (El-Dessouky & Ettouney 2002). Operating pressure is adjusted to overcome the effects of the following:

- osmotic pressure
- friction losses
- membrane resistance
- permeate pressure

An operating pressure equal to the sum of the above mentioned resistances will result in the net permeate flow rate to be zero. The operating pressure is therefore set at a higher value, typically 5 to 10bar higher, than the osmotic pressure of the final concentrate, in order to maintain economical permeate flow (El-Dessouky & Ettouney 2002).

3.5.1.2 Salt Rejection and Salt Passage

Salt rejection (SR) is the term used to describe what percentage of an influent species a membrane retains. For example, 96% rejection of calcium means that the membrane will retain 96% of the influent calcium which in turn means that 4% of the influent calcium will pass through the membrane into the permeate (salt passage). Rejection of given species is obtained by using equation 3.5.1.2a (Kucera 2010).

$$\%\,\boldsymbol{Rejection\ (SR) = [(C_F - C_P)/C_F] \times 100} \qquad \textit{equation 3.5.1.2a}$$

$$\boldsymbol{SR = [1 - C_P/C_F] \times 100}$$

Salt passage (SP) is the opposite of salt rejection and is obtained by equation 3.5.1.2b.

$$\%\, Salt\ passage\ (SP) = 100 - \%\, Rejection \qquad \textit{equation 3.5.1.2b}$$

$$\%\, SP = 100 - [(C_F - C_P)/C_F] \times 100$$

$$\%\, SP = (C_P/C_F) \times 100$$

where,

C_f feed (influent) concentration (TDS/conductivity) of a specific component

C_p permeate (effluent) concentration (TDS/conductivity) of a specific component

T temperature (K)

C_i concentration of constituent i in the water (mol/m^3)

3.5.1.3 Recovery

Recovery (R) is a term used to describe the percentage of influent water that is recovered as permeate. Recovery in RO systems typically range from about 35% to 45% for sea water. Recovery is obtained by the equation 3.5.1.3.

$$\boldsymbol{R = (Q_p/Q_f) \times 100} \qquad \textit{equation 3.5.1.3}$$

where,

Q_p permeate water flow rate

Q_f feed water flow rate

3.5.1.4 Concentration Factor

The CF is the ratio between the feed and concentrate (brine) salt concentration (total dissolved solids (TDS)/conductivity) and is obtained by applying equation 3.5.1.4a.

$$\boldsymbol{CF = (1 + (R \cdot SR) - R)/(1 - R)} \qquad \textit{equation 3.5.1.4a}$$

The salt rejection is usually higher than 97% (over the complete RO unit), therefore the CF can be estimated using the following more simple equation 3.5.1.4b.

$$\boldsymbol{CF = C_c/C_f \approx 1/(1 - R)} \qquad \textit{equation 3.5.1.4b}$$

where,

C_c concentrate (brine) concentration (TDS/conductivity)

3.5.1.5 Flux

Flux (J) is defined as the volumetric flow rate of a fluid through a given membrane, in the case of an RO system the fluid is water and the area that of the membrane. Flux is typically expressed as litre per square meter of membrane area per hour (LMH [litre/m^2.h]) or gallons per square foot of membrane area per day (GFD [gal/ft^2.day]). The flux through an RO membrane is proportional to the net pressure driving force applied to the water and can be expressed by the following simple equation 3.5.1.5 which will be discussed in more detail in the next section.

$$\boldsymbol{J = K(\Delta P - \Delta \pi)} \qquad \textbf{\textit{equation 3.5.1.5}}$$

where,

J	flux
K	water transport coefficient
ΔP	transmembrane pressure difference
$\Delta \pi$	transmembrane osmotic pressure difference

Water transport is unique to a given membrane and is not a constant but varies with temperature as explained in the next section on transfer through RO membranes.

3.5.2 Transfer through Reverse Osmosis Membranes

3.5.2.1 Driving Force

The driving force that causes the water to migrate through the RO membrane is, as mentioned, the mechanical pressure difference between the feed-to-concentrate and the permeate sides minus the osmotic pressure difference between the feed to concentrate and permeate sides. The flow rate of water through the membrane to the permeate side (flux) can be described in mathematical form as shown in equation 3.5.2.1a, which is an extension of equation 3.5.1.5.

$$\boldsymbol{Q_{pw} = K_{mw} K_T A(\Delta P - \Delta \pi)} \qquad \textbf{\textit{equation 3.5.2.1a}}$$

where,

Q_{pw}	water migration rate through the membrane to permeate
K_{mw}	membrane permeability coefficient for water
K_T	temperature coefficient
A	membrane area

The driving force that causes salts to migrate through the RO membrane is the difference in salt concentration between the feed-to-concentrate and the permeate sides. In mathematical form it can be expressed as shown here by equation 3.5.2.1b

$$\boldsymbol{Q_{ps} = K_{ms} K_T A(\Delta C)} \qquad \textbf{\textit{equation 3.5.2.1b}}$$

where,

Q_{ps}	salt migration rate through the membrane to permeate
K_{ms}	membrane permeability coefficient for salt
$\mathrm{K_T}$	temperature coefficient
A	membrane area
ΔC	concentration difference of salts across the membrane $(C_M - C_P)$

From equation 3.5.2.1b it is clear that pressure difference does not play any role in the migration of salts across the membrane.

3.5.2.2 Important Flux and Permeate Quality Observations

The concentration of salt in the permeate stream can be obtained from equation 3.5.2.2 which is derived from equations 3.6.2.1a and 3.6.2.1b.

$$\boldsymbol{C_p = \frac{Q_{ps}}{Q_{pw}} = \frac{K_{ms} K_T A(C_m - C_p)}{K_{mw} K_T A(\Delta P - \Delta \pi)}} \qquad \textbf{\textit{equation 3.5.2.2}}$$

This equation highlights the following important aspects:

- Increase in feed pressure will increase permeate water flow and decrease permeate salinity.
- Increase in water temperature will increase both permeate water flow rate and salt flow rate and will therefore not affect permeate salinity (but note that an increase in temperature will, however, decrease the viscosity of the water, requiring lower feed pressures to maintain the same flux which will then result in an increase in permeate salinity if the flux remains the same.
- Increase in feed salinity will decrease permeate flow rate (due to increased osmotic pressure difference), increase permeate salt flow (due to increased concentration difference) and therefore increase permeate salinity.
- An increase in concentration polarization *will increase* C_M (and therefore ΔC) and will then increase $\Delta\pi$ with a resultant decrease in permeate flow rate and an increase in permeate salinity.

3.5.3 Normalisation of SWRO Performance Data

Normalisation of RO membrane salt passage and flux data are important for RO plant design, performance efficiency calculation and quality assurance. Normalisation of RO data is also in line with the World Health Organisation (WHO) as well as other standards. Normalisation is the process of standardising actual data to a set of fixed conditions at constant, temperature, concentration and pressure using correction factors (Jamaluddin *et al.* 2001).

Normalisation with reference to the initial system performance is useful to highlight any performance changes between day one and the actual date. Normalisation with reference to the designed system performance is useful to verify that the plant gives the specified performance. Plant performance normalisation allows for the early identification of potential problems (for example scaling or fouling) when normalised data are recorded daily.

The plant performance normalisation method as described in the DOW Water & Process Solutions, FILMTEC™ Reverse Osmosis Membranes Technical Manual (DOW 2012), will be used and is described in this section.

3.5.3.1 Normalised Permeate Flow

The normalised permeate flow is described by equation 3.5.3.1a.

$$\boldsymbol{Q_s} = \boldsymbol{Q_o} \cdot \frac{\boldsymbol{TCF_s}}{\boldsymbol{TCF_o}} \cdot \frac{\boldsymbol{P_{fs} - \frac{\Delta P_{fbs}}{2} - P_{ps} - \pi_{fbs} + \pi_{fbs}}}{\boldsymbol{P_{fo} - \frac{\Delta P_{fbo}}{2} - P_{po} - \pi_{fbo} + \pi_{fbo}}} \qquad \textit{equation 3.5.3.1a}$$

where,

P_f	feed pressure
ΔP_{fb}	device pressure drop
P_p	permeate pressure
π_{fb}	feed-brine osmotic pressure
π_p	permeate osmotic pressure
Q	product flow
TCF	temperature correction factor
s	standard conditions
o	operating conditions

In an interesting study by Jamaluddin *et al.* (2001) a new method for determining the pressure correction factor (PCF) was investigated and an alternative method was developed for determining osmotic pressure directly from conductivity measurements. This method was

proven to be simpler and more accurate than the use of linear factor with TDS, which is the conventional method for determining osmotic pressure. In the study by Jamaluddin *et al.* (2001) data were normalised from actual operating conditions to standard reference test conditions of feed pressure 56 kg/cm^2, feed temperature of 25°C and a feed concentration of 35 000 mg/litre NaCl. The temperature correction factor (TFC) is determined by equation 3.5.3.1b or 3.5.3.2c.

$$\boldsymbol{TCF = e^{[K_{wt}(1/298 - 1/(273+T))]};\ T \geq 25°C} \qquad \textbf{equation 3.5.3.1b}$$

$$\boldsymbol{TCF = e^{[K_{wt}(1/298 - 1/(273+T))]};\ T \leq 25°C} \qquad \textbf{equation 3.5.3.1c}$$

where,

T temperature as °C

K_{WT} temperature coefficient for water transport

As standard conditions, either the design values or the conditions at initial performance are used so that a fixed reference point is available. The temperature coefficient for water transportation differs with the type of membrane used. Temperature coefficients as recommended by manufacturers are:

$$K_{WT}(Nitto\ Denko) = 2700$$

$$K_{WT}(Fluid\ System) = 2600\ (for\ TFCL/TFCS\ membranes)$$

$$K_{WT}(FilmTech) = 3020\ at\ T < 25°C,\ 2640\ at\ T > 25°C$$

$$TCF_{\ Toray} = 2.176e^{-0.0311T}$$ (derived by Jamaluddin et al. 2001)

While the TCF supplied by Du Pont is:

$$TCF\ DuPont = 1.08(T - 25)$$

The osmotic pressure of feed, feed-brine and permeate are calculated utilising equations 3.5.3.1d, 3.5.3.1e and 3.5.3.1f taken from ASTM D4516 (ASTM 2010) respectively.

$$\boldsymbol{\pi_f = 8.308\ \varphi\ (Tf + 273.15)\ \Sigma m_i} \qquad \textbf{equation 3.5.3.1d}$$

$$\boldsymbol{\pi_{fb} = 0.2654\ C_{fb}(T + 273.15)/(1000 - C_{fb}/1000)} \qquad \textbf{equation 3.5.3.1e}$$

$$C_{fb} = C_f \cdot \frac{ln\frac{1}{1-R}}{R} \qquad \textit{equation 3.5.3.1e(i)}$$

$$C_{fb} = \frac{1}{2}(C_f + C_b) \qquad \textit{equation 3.5.3.1e(ii)}$$

$$\pi_p = 0.01\pi_{fb} \qquad \textit{equation 3.5.3.1f}$$

where,

π_f	feed osmotic pressure in kPa
π_{fb}	feed-brine osmotic pressure in kPa
π_p	permeate osmotic pressure in kPa
φ	osmotic coefficient for sea water (estimates 0.9)
T_f	temperature of feed stream at °C
Σmi	summation of molality of all ionic and non-ionic constituents in the sea water
C_{fb}	concentration of feed-brine as mg/litre NaCl
C_f	concentration of feed as mg/litre NaCl
C_b	concentration of brine as mg/litre NaCl
R	recovery ratio

Concentrations of salt equivalent as NaCl in the SWRO feed and brine ($C_f + C_b$) can be calculated using equations 3.5.3.1g and 3.5.3.1h if not measured.

$$C_f = 1000\pi_f / [0.2654(T_f + 273.15) + \pi_f/1000] \qquad \textit{equation 3.5.3.1g}$$

$$C_b = \frac{C_f(1-SP.R)}{(1-R)} \qquad \textit{equation 3.5.3.1h}$$

Jamaluddin *et al.* (2001) calculated respective osmotic pressures from the summation of molalities (Van't Hoff equation) of individual ions present in water, utilising equation 3.5.3.1i. It was then established that osmotic pressures versus corresponding conductivities result in the following second order quadratic equation:

$$\pi = 0.0032C^2 + 0.1421C + 9.9534 \qquad \textit{equation 3.5.3.1i}$$

where,

C	conductivity in ms/cm
π	osmotic pressure in bar

In the study by (Jamaluddin *et al.* (2001) this equation was verified in several cases and found to yield 99% correct results compared to osmotic pressure calculation utilising analytical results.

Another approximation of the feed osmotic pressure suggested in the *DOW Water & Process Solutions, FILMTEC™ Reverse Osmosis Membranes, Technical Manual* (DOW 2012) is summarised by equations 3.5.3.1j and 3.5.3.1k.

$$\pi_{fb} = \frac{C_{fb}\cdot(T+320)}{491000}\ bar\ \ (C_{fb} < 20\,000\ mg/litre) \qquad \textit{equation 3.5.3.1j}$$

$$\pi_{fb} = \frac{0.0117\cdot C_{fb}-34}{14.23}\cdot\frac{T+3204}{345}\ bar\ \ (C_{fb} > 20\,000\ mg/litre) \qquad \textit{equation 3.5.3.1k}$$

3.5.3.2 Normalised Permeate Total Dissolved Solids

The normalised TDS is calculated from the following equation 3.5.3.2:

$$C_{ps} = C_{po}\cdot\frac{P_{fo}-\frac{\Delta P_{fbo}}{2}-P_{po}-\pi_{fbo}+\pi_{po}}{P_{fs}-\frac{\Delta P_{fbs}}{2}-P_{ps}-\pi_{fbs}+\pi_{ps}}\cdot\frac{C_{fbs}}{C_{fbo}} \qquad \textit{equation 3.5.3.2}$$

where,

C_p product/permeate concentration as mg/litre NaCl

3.5.4 Reverse Osmosis Membranes

The ideal RO membrane should offer high flux and high rejection rates in addition to high strength and durability. History shows that high rejection and high flux have, up until recently, been two mutually exclusive goals and that the one would always benefit at the cost of the other. Although most recent membranes have seen an increase in flux without any decrease in rejection most of the membranes used today represent a compromise between rejection and flux (Kucera 2010). The two most common families of RO membranes are cellulose acetate (asymmetric) and polyamide (composite) membranes (Kucera 2010; El-Dessouky & Ettouney 2002). A lot of research has been done on different membrane materials as well as different membrane modules (e.g. hollow fibre and spiral wound), the reader is referred to Appendix A for more detail on this. The membrane used for this study is a spiral wound DOW FILMTEC SW30-2540 membrane.

3.5.5 UF and RO Membrane Cleaning

The surface of UF and RO membranes are subjected to fouling by foreign materials that may be present in the feed water, such as hydrates of metal oxides, calcium precipitates, organics and biological matter. The term 'fouling' includes the build-up of all kinds of layers on the membrane surface, including scaling. Occasionally, fouling of the membrane surfaces is caused by:

- an inadequate pre-treatment system
- pre-treatment upset conditions
- improper selection of materials (pumps, piping, *etcetera*)
- failure of chemical dosing systems
- inadequate flushing following shutdown
- improper operational control
- slow build-up of precipitates over extended periods (barium, silica *etcetera*)
- change in feed water composition
- biological contamination of feed water

The fouling of membrane surfaces manifests itself in lower permeate flow rate and/or a higher solute passage. Another side effect of membrane fouling is an increased trans membrane pressure (TMP) drop, for UF membranes, and an increased pressure drop between the feed and concentrate side, for RO membranes. It also results in higher RO pressures.

In normal operation, the membranes in RO elements can become fouled by mineral scale, biological matter, colloidal particles and insoluble organic constituents. Deposits build up on the membrane surfaces during operation. This causes the loss of normalised permeate flow, loss of normalised salt rejection – or both.

It is essential to clean UF and RO membranes at an early stage of fouling. It is often difficult to clean excessively fouled membranes and irreversible damage may occur during the cleaning process. Elements should be cleaned with a suitable membrane cleaning solution when one or more of the following parameters are applicable (DOW 2012):

- The normalised permeate flow drops with 10%
- The normalised salt passage increases with 5 - 10%
- The normalised pressure drop increases with 10 - 15%.

If one waits too long and any of the above performance parameters deteriorate by more than 30%, it may be impossible to recover plant performance by routine cleaning practices using a membrane cleaning solution. For RO membranes differential pressure (∆P) should be measured and recorded across each stage of the array of pressure vessels (in this study there is only one stage with one membrane). If the feed channels within the element become plugged, the ∆P will increase. It should be noted that the permeate flux will drop if feed water temperature decreases. This is normal and does not indicate membrane fouling.

Two types of chemically enhanced cleaning are applied when considering UF and RO membranes. The first is chemically enhanced backwashing (CEB), which is applicable only to UF membranes and the second is cleaning-in-place (CIP), applicable to both UF and RO membranes.

3.5.5.1 Chemically Enhanced Backwash (UF Membranes)

To avoid the formation of a thick fouling layer, the system needs to be backwashed in defined intervals. In backwash mode, filtrate is pressed from the filtrate to the concentrate side of the membrane, hereby removing the fouling substances attached to the concentrate side of the membrane. The filtrate is stored in a buffer tank between the UF pilot plant and the RO feed tank from where the filtrate can be used for backwashing.

Backwashing with filtrate alone does not always remove the foulants completely, resulting in a decrease in filtration performance. To better recover the system's original filtration performance, chemically enhanced backwashes are applied. The CEB frequency is dependent on the feed water quality and can be determined on-site. Keeping in mind the type of foulant, the appropriate chemical cleaning substance is chosen – typically a high pH backwash (sodium hydroxide and chlorine) followed by a low pH backwash (hydrochloric acid or citric acid) is used. The CEB cleaning solution applied during this study will be elaborated on in chapter 4 of this dissertation.

3.5.5.2 Cleaning In Place (UF and RO Membranes)

CIP is a more thorough but lengthy cleaning process which is done less often than CEB – only every 1 to 2 months depending on the rate of fouling of the membranes. A ClP with any specific cleaning solution usually involves the following six steps (DOW 2012):

1. Make up cleaning solution.

2. Low-flow pumping. Pump mixed, preheated cleaning solution into the vessel at conditions of low flow rate and low pressure to displace the process water (as prescribed by

membrane manufacturers). Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that no or little permeate is produced. A low pressure minimizes re-deposition of dirt on the membrane. Dump the concentrate as is necessary – to prevent dilution of the cleaning solution.

3. Recycle. After the process water is displaced, cleaning solution will be present in the concentrate stream. Recycle the concentrate and permeate to the cleaning solution tank and allow the temperature to stabilise. Measure the pH of the solution and adjust the pH if needed.

4. Soak. Turn the pump off and allow the elements to soak. Sometimes a soak period of about 1 hour is sufficient. For difficult fouling an extended soak period is beneficial – soak the elements overnight for 10 to 15 hours. To maintain a high temperature during an extended soak period, use a slow recirculation rate (as prescribed by membrane manufacturers).

5. High-flow pumping. Feed the cleaning solution at the rates prescribed by membrane manufacturers for 30-60 minutes. The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. At higher flow rates, excessive pressure drop may be a problem and one should be aware of the limits on pressure drop as prescribed by membrane manufacturers.

6. Flush out. RO permeate or deionised water is recommended for flushing out the cleaning solution. Pre-filtered raw water or feed water should be avoided as its components may react with the cleaning solution: precipitation of foulants may occur in the membrane elements. The minimum flush out temperature is 20°C.

There are a number of factors involved in the selection of a suitable cleaning solution and protocol. It is not unusual to use a number of different cleaning chemicals in a specific sequence to achieve the optimum cleaning. Typically, a high pH cleaning is used first to remove foulants like oil or biological matter, followed by a low pH cleaning to remove foulants like mineral scale or metal oxides/hydroxides. The order of high and low pH cleaning solutions can be reversed or only one solution can be required. Some cleaning solutions have detergents added to aid in the removal of heavy biological and organic debris. Others have a chelating agent like ethylene-diamine-tetra-acetic acid (EDTA) added to aid in the removal of colloidal material, organic and biological material, and sulphate scale. The CIP solution applied during this study will be elaborated on in chapter 4 of this dissertation.

Table 3.5.5.2 summarises a range of cleaning solutions and the specific foulants that is targeted.

Table 3.5.5.2 *– CIP: membrane cleaning solutions*

CLEANING SOLUTION / FOULANT	INORGANIC SALTS	SULFATE SCALES	METAL OXIDES / HYDROXIDES	COLLOIDAL MATERIAL	SILICA	BIOFILMS	ORGANIC
0.1% (W) NaOH or 1.0% (W) Na4EDTA (pH 12, 35°C maximum)		*Good*			*Moderate*	*Moderate*	*Moderate*
0.1% (W) NaOH or 0.025% (W) Na-DSS (pH 12, 35°C maximum)				*Good*	*Good*	*Good*	*Good*
0.1% (W) of NaOH (pH 11.5, 35°C maximum)					*Good*		
0.1% (W) of NaOH and 0.03% (W) of SDS (sodium dodecylsulfate) (pH 11.5, 35°C maximum)				*Good*		*Good*	*Good*
2.0% (W) of Na5P3O10 (STPP - sodium tripolyphosphate) and 0.025% (W) C6H5(CH2)12-SO3Na (Na-DDBS - sodium salt of dodecylbenzene sulfonate) (pH 10, 35°C maximum)							*Good*
2.0% (W) Na5P3O10 (STPP - sodium tripolyphosphate) and 0.8% (W) of Na-EDTA (sodium salt of ethylaminediaminetetraacetic acid) (pH of 10.0, 35°C maximum)	*Good*						*Moderate*
1.0% (w) of Na2S2O4 (sodium hydrosulfite) (natural pH 4 - 6 ; no pH adjustment is required)	*Moderate*		*Good*				
1.0% (W) Na2S2O4 (sodium hydrosulfite), (pH 5, 25°C maximum)	*Moderate*		*Good*				
1.0% (W) NH2SO3H , 25°C and pH 3 - 4			*Moderate*				
0.5% (W) of HCl (hydrochloric acid) (pH 2.5, 25°C maximum)	*Good*		*Good*	*Good*			
0.2% (W) HCl (pH 1-2, 25°C maximum)	*Good*						
0.5% (W) H3PO4 (pH 1-2, 25 °C maximum)	*Moderate*		*Moderate*				
2.0% (W) citric acid (C6H8O7) (pH 1-2 , 25°C maximum)	*Good*		*Good*	*Good*			

3.6 Summary

From the literature review on desalination several aspects important to this study should be highlighted:

- The abalone farm intake system is comparable to an open water shoreline intake system followed by settling tanks (which are the abalone tanks in this case).

- The SDI and MFI tests are mostly used in the field for estimating the fouling potential of RO feed water. This estimation is a prerequisite to control membrane fouling successfully and to evaluate the effectiveness of the applied pre-treatment. The $MFI_{0.45}$ test has overcome many of the SDI deficiencies, is based on the occurrence of cake filtration, has a linear relation with particle matter content, and is corrected for temperature and pressure. The MFI test is therefore used in this study.

- Turbidity is caused by colloidal particles and is measured in the study to estimate and compare the colloidal concentration and fouling potential of the water at different points on the abalone farm and pilot plant.

- Foulants identified and discussed include inorganic, particulate, bio-, and organic foulants as well as TEP.

- Antiscalant prevents saturated salts from precipitating (inorganic fouling) and is dosed before the RO membrane in the pilot study. Antiscalant should be dosed to give a concentration in the concentrate stream of 20 mg/l (DOW 2012).

- DBNPA is biocide compatible with RO membranes typically sensitive to free chlorine. DBNPA is highly effective, non-oxidizing and more environmentally friendly than typical biocides. To prevent biofouling DBNPA is applied in the pilot study at the prescribed dosing rate of 50 – 170 mg/litre of the 20% active ingredients product for 30 minutes to 3 hours, every 5 days (DOW 2012).

- Coagulation and flocculation processes are used to prevent particulate and organic fouling by aiding the removal of suspended particles and some dissolved organics The coagulant most frequently used for desalination plants is iron(III)chloride ($FeCl_3$) (Fritzmann *et al.* 2007). Jeong *et al.* (2011) proved in their study on the performance of iron(III)chloride as flocculent that the highest DOC removals, 57%, were obtained at a concentration of 3 mg/litre as Fe^{3+}. The membrane fouling behaviour of the UF

and RO is investigated with and without iron(III)chloride dosing at 3 mg/litre (as Fe^{3+}) during the pilot study.

- Literature reveals that the difference between media filtration and membrane filtration as pre-treatment option is growing ever smaller. The choice between the two pre-treatment methods comes down to what suites the specific site and feed water source the best. Conventional media filtration is a more robust process, but does however produce a lower quality permeate if not operated correctly. Membranes act as a definite barrier between the RO system and any suspended particles. It is particularly advantageous to RO systems treating surface water (such as the open sea water intake of the abalone farm) since these water sources tend to contain more organic colloidal and suspended matter than underground water (such as the water from beach wells). These water sources are also subject to higher variability and sporadic problematic events such as algal blooms which are better handled by membrane pre-treatment than the conventional methods (Greenlee *et al.* 2009). Ultrafiltration is therefore used as pre-treatment method in the pilot study.

- CEB is applied to the UF membrane to better recover the systems original filtration performance. The CEB frequency is dependent on the feed water quality and can be determined on-site. The pilot study is started with a CEB frequency of once every 24 hours. SMBS dechlorination is required after CEB. SMBS must be applied at a concentration 3 mg/litre of SMBS per 1 mg/litre of free chlorine (Fritzmann *et al.* 2007).

CHAPTER 4

4. RESEARCH DESIGN AND METHODOLOGY

"Failing to plan is planning to fail"
- ALAN LAKEIN

Based on the information from literature the research design and methodology used in this study, to obtain the required results and to finally reach the conclusions made, are discussed in this chapter.

4.1 APPROACH

From the literature study four aspects that need to be addressed, to determine the feasibility and viability of cost effectively integrating a sea water reverse osmosis (SWRO) desalination plant with a typical South African abalone farm, can be identified. These aspects follow logically from the aims and objectives of this dissertation and they are as follows:

1. Characterisation of typical South African abalone farm water.
    - Investigation of the effect of individual abalone tanks on sea water quality.
    - Characterisation of the combined abalone farm influent and effluent.
    - Investigation of the seasonal effects on abalone farm sea water quality.

2. SWRO desalination plant pilot study and membrane fouling behaviour.
    - Investigation of the overall performance of an SWRO desalination pilot plant with abalone farm effluent as feed water.
    - Investigation of the membrane fouling behaviour of abalone farm effluent.
    - Investigation into the effect of flocculation on UF membrane behaviour.

3. General operation of a typical abalone farm and its implications for desalination.
    - Obtain a better understanding of the typical operation and management procedures on an abalone farm.
    - Identify and address possible problem areas for the integration of an abalone farm with a desalination plant.
    - On-site experience will also help to identify possible abnormal events that may hinder the integration process.

4. Cost estimates and implications for the integration of an SWRO plant with an abalone farm.

- Review available literature pertaining to the cost of SWRO desalination and more specifically intake systems.
- Determine the unit production cost (UPC) of desalinated water.
- Investigate typical cost breakdown structure to determine percentage contribution of intake systems to the desalinated UPC water.

4.2 CHARACTERISATION OF SOUTH AFRICAN ABALONE FARM SEA WATER

In this project it is proposed that effluent water from a typical abalone farm be used as feed water for a desalination plant to save costs by sharing an intake system with the abalone farm. Therefore, water from the abalone farm was characterised by measuring parameters at different sampling points over a period of nine months from October 2011 up to July 2012.

In order to place the water characterisation study into perspective the abalone tank configuration and the layout of the designated area of the farm investigated are discussed here before elaborating on the actual water characterisation procedures that were followed.

4.2.1 Individual Abalone Tank Configuration

The abalone tank configuration used on a typical abalone farm consists of a single abalone tank receiving fresh sea water at one end and overflowing at the opposite end. For this system two possible points of abstraction are (1) the influent (raw sea water filtered with 1000 µm drum screens) and (2) the abalone tank effluent (see figures 4.2.1 and 4.2.2).

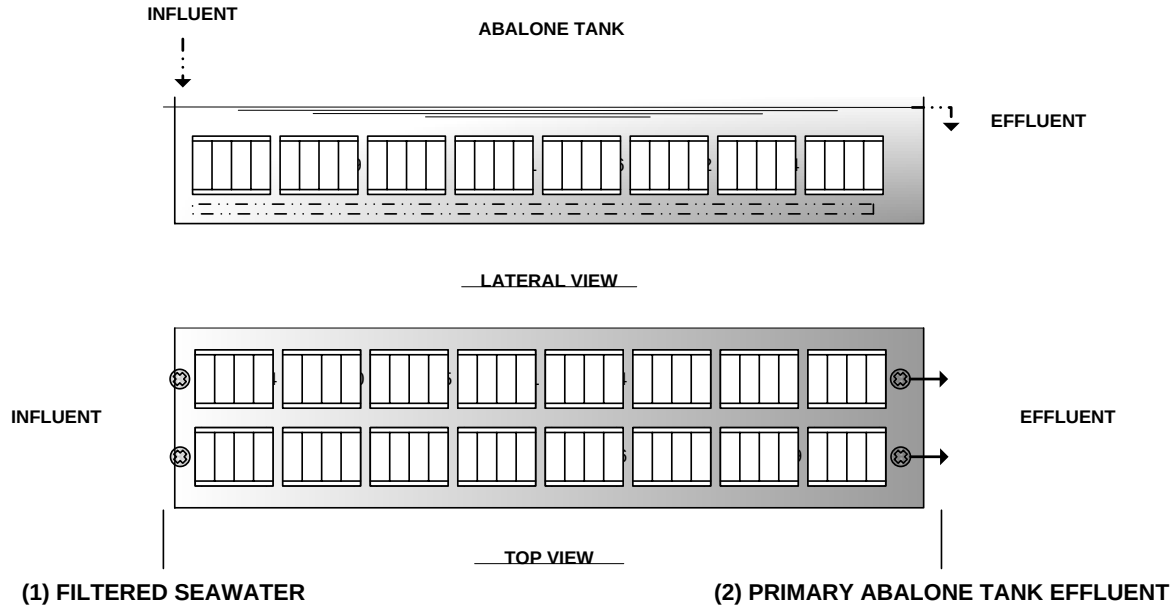

Figure 4.2.1 *– Individual abalone tank configuration*

Ideally one would use the effluent from these abalone tanks for desalination, since this would require no increase in the intake capacity for the farm. The effluent sea water was already used by the farm and simply gravitates back into the ocean. However, it is important to determine the effect of the individual abalone tanks on the quality of the sea water. Both the influent and effluent streams from the individual abalone tanks were therefore investigated during the water characterisation study.

In order to do research with as little as possible interference with the everyday abalone farming activities, a smaller designated study area had to be identified to serve as a representation of the entire abalone farm. The effects of the individual tanks in this area on the quality of the sea water flowing through them were investigated and compared. This was done to confirm that there was little difference between the individual tanks from and that the forty tanks in the designated area were in fact representative of the entire farm.

4.2.2 Designated Area for Water Characterisation

The entire designated area for the conventional system consisted of four rows of cement abalone tanks with ten tanks per row, thus forty abalone tanks. Water flow rates through the abalone tanks range between 15 – 25 litre/(kg abalone)/h with each tank containing between the 192 – 256 kg abalone. That gives a flow rate of between 2880 – 6400 litre/h through each tank.

Figure 4.2.2 shows a schematic represention of the designated area, as seen from above. The possible sampling points are at the inlet and outlet of each tank as well as the combined influent and effluent streams.

Figure 4.2.2 *– Designated area for water characterisation: abalone tank layout*

In figure 4.2.2 the circles (indicated only on tank 122A1) represent the sampling points for an individual tank whereas the squares represent the sampling points for the (1) combined influent stream and the combined (2) effluent stream.

It is important to thoroughly characterise the water over an extended period of time, through seasonal changes, before finalising the pilot plant design, the building thereof and finally then commissioning it. The scope of the project unfortunately does not allow time for this. Some of the water characterisation was therefore done in 2011 whilst simultaneously designing and building the pilot plant. Water characterisation was continued in 2012 after commissioning the pilot plant to help explain the performance and behaviour of the pilot plant.

4.2.3 Individual Abalone Tank Water Characterisation

Water characterisation parameters of the individual abalone tanks were measured over a period of almost seven months from 19 October 2011 up to 26 April 2012 to establish the effect of individual abalone tanks on the sea water flowing through. The results from the different individual abalone tanks were then compared to determine the extent to which the tanks in the designated area could represent the entire abalone farm.

Table 4.2.3 is a summary of the water quality parameters measured for the individual abalone tanks, the sampling sites on the individual abalone tanks that were measured and the period during which each parameter was measured during the study. Instrument details can be found in Appendix D.

Table 4.2.3 *– Individual abalone tank water characterisation parameters*

INSTRUMENT AND PARAMETER	UNITS	SAMPLING SITES	PERIOD
YSI Professional Plus Multi-meter			
Temperature	*°C*	*influent and effluent*	*19/10/2011 - 26/04/2012*
Conductivity	*µS/cm*	*influent and effluent*	*19/10/2011 - 26/04/2012*
Specific Conductivity	*µS/cm*	*influent and effluent*	*19/10/2011 - 26/04/2012*
Total Dissolved Solids (TDS)	*mg/litre*	*influent and effluent*	*19/10/2011 - 26/04/2012*
Dissolved Oxygen (DO)	*mg/litre*	*influent and effluent*	*19/10/2011 - 26/04/2012*
pH	*-*	*influent and effluent*	*19/10/2011 - 26/04/2012*
HANNA HI98703 Turbidity Meter			
Turbidity	*NTU*	*influent and effluent*	*19/10/2011 - 26/04/2012*
MFI Equipment			
$MFI_{0.45}$ (ASTM D4189-07)	*$s/litre^2$*	*influent and effluent*	*19/10/2011 - 26/04/2012*

Individual abalone tank parameters were measured on the following dates during this period: *19/10/2011; 18,23/01/2012; 20,27/03/2012; 3,19,26/04/2012*.

The effects of seasonal changes during this period from spring to summer to autumn could therefore be investigated.

4.2.4 Combined Streams Water Characterisation

Water characterisation parameters of the combined streams were measured over a period of almost four months from 20 March 2012 to 9 July 2012 using the same instruments as for the individual abalone tank water characterisation.

The influent stream is sampled from the main line supplying the four abalone tank rows investigated (top left square in Figure 4.2.2); the effluent stream is the combined effluent stream from all forty abalone tanks and is sampled from the gulley where it is collected (top right square in Figure 4.2.2); the effluent$_{200\mu m}$ is the combined effluent stream sampled after filtration through a primary 200µm screen (see figure 4.3). Table 4.2.4.1 summarises the water characterisation parameters measured for the combined sea water streams.

Table 4.2.4.1 *– Combined streams water characterisation parameters*

INSTRUMENT AND PARAMETER	UNITS	SAMPLING SITES	PERIOD	FREQUENCY
YSI Professional Plus Multi-meter				
Temperature	*°C*	*influent, effluent and effluent$_{200\mu m}$*	*20/03/2012 - 9/07/2012*	*Daily*
Conductivity	*µS/cm*	*influent, effluent and effluent$_{200\mu m}$*	*20/03/2012 - 9/07/2012*	*Daily*
Specific Conductivity	*µS/cm*	*influent, effluent and effluent$_{200\mu m}$*	*20/03/2012 - 9/07/2012*	*Daily*
Total Dissolved Solids (TDS)	*mg/litre*	*influent, effluent and effluent$_{200\mu m}$*	*20/03/2012 - 9/07/2012*	*Daily*
Dissolved Oxygen (DO)	*mg/litre*	*influent, effluent and effluent$_{200\mu m}$*	*20/03/2012 - 9/07/2012*	*Daily*
pH	*-*	*influent, effluent and effluent$_{200\mu m}$*	*20/03/2012 - 9/07/2012*	*Daily*
HANNA HI98703 Turbidity Meter				
Turbidity	*NTU*	*influent, effluent and effluent$_{200\mu m}$*	*20/03/2012 - 9/07/2012*	*3 times/week*
MFI Equipment				
$MFI_{0.45}$	*$s/litre^2$*	*influent, effluent and effluent$_{200\mu m}$*	*20/03/2012 - 9/07/2012*	*3 times/week*

Water samples were also sent for analysis to the Council for Scientific and Industrial Research (CSIR) at their ISO17025 accredited laboratories in Stellenbosch. Table 4.2.4.2 is a summary of the water characterisation parameters analysed by the CSIR laboratories.

Table 4.2.4.2 *– water characterisation parameters analysed by the CSIR laboratories*

PARAMETER	UNITS	SAMPLING SITES	SAMPLING DATES
Physical and organoleptic requirements			
Specific Conductivity	*µS/cm*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
pH		*influent and effluent*	*30/04/2012; 9,25/06/2012*
Total Dissolved Solids (TDS)	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Macro Determinants			
Cations and Anion Balance	*-*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Potassium as K	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Sodium as Na	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Calcium as Ca	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Magnesium as Mg	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Ammonia as N	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Sulphate as SO4	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Chloride Cl	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Alkalinity as CaCO3	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Fluoride as F	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Nutrients			
Nitrate plus Nitrite as N	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Nitrate as NO3	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Nitrite as NO2	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Ortho phosphate as P	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Dissolved Organic Carbon (DOC)	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Kjeldahl Nitrogen as N	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Metals			
Boron as B Dissolved	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Silica as Si Dissolved	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Strontium as Sr Dissolved	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Bomide as Br Dissolved	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Iron as Fe Dissolved	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*
Manganese as Mn Dissolved	*mg/litre*	*influent and effluent*	*30/04/2012; 9,25/06/2012*

4.2.5 Total Dissolved Solids and Salinity

Total dissolved solids (TDS) consist of minerals, organic matter, and nutrients that have dissolved in water - the ions and compounds that you cannot see in the water. Walton (1989) investigated the relationship between conductivity and TDS throughout the range of water found in the desalination industry and shows that for water in the range between 45 000 – 60 000 µS/cm a multiplier with a value of 0.7 can be used to convert specific conductance in

µS/cm to TDS in mg/litre. The value of 0.7 was therefore set on the YSI Professional Plus instrument when taking TDS measurements from the abalone tanks. This approximation is considered to be reasonably accurate seeing that the water specific conductivity for the influent and effluent abalone tank streams ranged between 50 000 and 54 000 µS/cm.

Salinity is a measure of the mass of dissolved salts (ionic constituents) in a given mass of solution and is expressed as milligrams per litre (mg/litre). Conductivity measurements, along with temperature, allow for salinity values to be calculated through algorithms built into the YSI Pro Plus instrument. For more detail on the typical algorithms applied, the reader is referred to original work on this relationship by researchers such as Bennett (Bennett 1976) and Lewis (Lewis 1980).

4.2.6 Modified Fouling Index

Either the SDI or $MFI_{0.45}$ can be used to predict colloidal fouling behaviour of feed water. Although the SDI test has been applied worldwide for many years, because of its simplicity and low cost, there are growing doubts about its reliability (Alhadidi *et al.* 2011; Alhadidi *et al.* 2012). To overcome the SDI deficiencies, the $MFI_{0.45}$ has been developed. Although the procedure of measuring an $MFI_{0.45}$ is more complicated, it has many advantages over the SDI. The pros and cons of SDI and MFI are summarised in Table 4.2.6 (Nahrstedt & Camargo-Schmale, 2008; Alhadidi *et al.* 2011; Alhadidi *et al.* 2012).

Table 4.2.6 *– Advantages and disadvantages of SDI and MFI*

	ADVANTAGES	**DISADVANTAGES**
SDI	*Simple* *Standardised* *Can be performed in situ* *Established*	*Not based on a theory or model* *Empirical* *No linear relationship with the amount of foulant* *High permeation rate comparing with RO membranes* *Result very sensitive to operator and procedure* *Standardization incomplete*
MFI	*Linear relationship with foulant* *Based on cake filtration theory* *Different fouling mechanism can be observed* *Broader value range than SDI*	*More complex and more expensive than SDI* *Not independent of pressure*
SDI and MFI		*Only dead-end operation mode* *Fouling potential of particles <0.45um not considered* *Insufficient accuracy and precision*

Taking into account the deficiencies in the SDI method, the $MFI_{0.45}$ method is preferred. Besides the less simple procedure for the $MFI_{0.45}$ test another hurdle that needs to be considered is defining a similar guideline like SDI = 3 for $MFI_{0.45}$ (the SDI of RO feed water should preferably be lower than 3). In principle this guideline can be derived for $MFI_{0.45}$ by making use of the mathematical relationship between SDI and $MFI_{0.45}$ as derived by Aldahidi and others (Alhadidi *et al.* 2011). This only showed that it was not possible to get one distinct guideline value due to the strong dependency of SDI on membrane resistance. A wide range of $MFI_{0.45}$ values can therefore be equivalent to SDI = 3. Limiting the range of allowable membrane resistances according to ASTM reduces the equivalent $MFI_{0.45}$ guideline to the range of 0.6 - 2.4 s/litre^2.

Alhadidi *et al.* (2012) calculated the average reduction in the fouling potential of UF permeate relative to UF feed. They defined the reduction in $MFI_{0.45}$ values as the ratio of the difference between the feed and permeate values to the feed value. It was found that the particle removal based on the $MFI_{0.45}$ was 99.95±0.053%, which means that the MFI values of the UF feed were on average 0.05% of that of the UF permeate, which was to be expected.

In this study the $MFI_{0.45}$ values of the influent and effluent streams were measured, rather than the UF permeate, in order to determine possible differences in their fouling potential and it was assumed that the $MFI_{0.45}$ of the UF permeate would be in the order of 0.05% of these values. $MFI_{0.45}$ was therefore used as indicator of fouling on UF membranes.

The membranes used for the MFI tests were as prescribed by the *ASTM International Standard Test Method for Silt Density Index (SDI) of Water* (ASTM 2007). White hydrophilic, mixed cellulose nitrate (50 – 75%) and cellulose acetate (MCE) membranes were used with a mean pore size of 0.45 µm. The diameter of the filter was 47 mm nominal. Thickness was between 115 and 180 µm. Pure water flow time was 25 – 50 s for 500 ml under an applied pressure difference 91.4 – 94.7 kPa. Bubble point was 179 – 248 kPa and only filters that were packaged in the same orientation were used.

4.3 SWRO DESALINATION PILOT PLANT

The on-site pilot study was carried out over a period of six months from 8 February 2012 up to 9 July 2012.

Figure 4.3 shows a simple process flow diagram of the SWRO desalination pilot plant used in this study. Effluent sea water was pumped from the gulley where the effluent from all the tanks in the designated area was collected. This water was then passed through a 200 µm disk filter before it entered the storage tank from where the ultra-filtration unit was fed. The

storage tank level was set using a gooseneck to ensure a residence time of not more than two hours for the water in the tank. The residence time in this buffer tank was kept as short as possible to prevent unrealistic settling times and shifts in water temperature. Another reason for this was to prevent biological growth in the tank since no chlorine or biocide was dosed in the tank. From here the water is fed to the ultra-filtration unit. The backwash water from the ultra-filtration unit is returned to the gulley, which is situated lower downstream from the intake. The ultra-filtration permeate was stored in a 30 litre backwash buffer tank, which in turn overflowed into the 150 litre reverse osmosis feed tank from where the RO pilot unit was fed. The RO permeate was stored in a 150 litre tank for rinsing purposes while the concentrate was returned to the gulley, downstream from the intake.

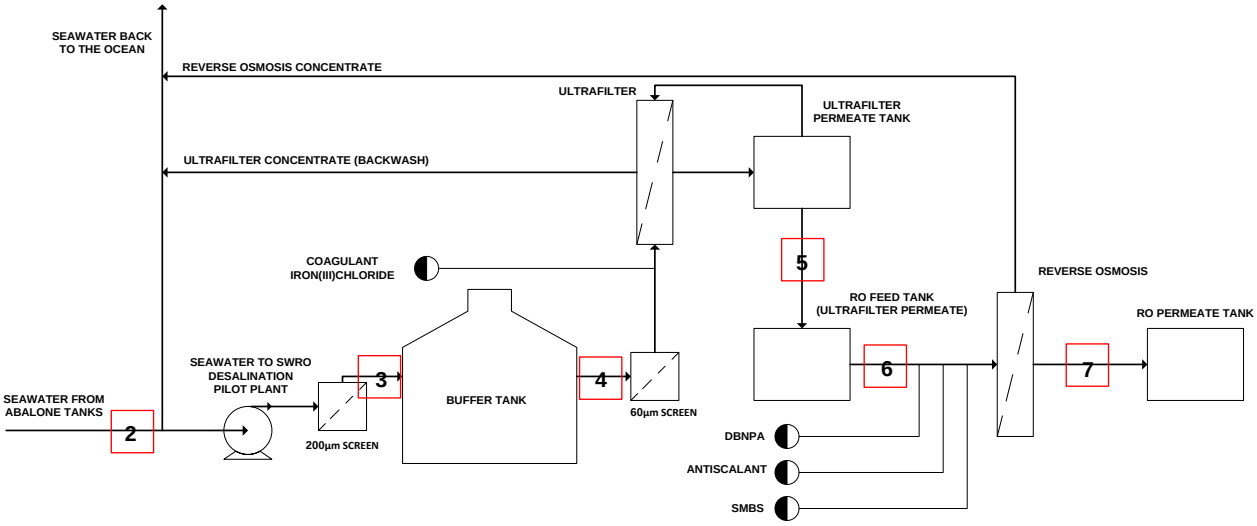

Figure 4.3 *– SWRO desalination pilot plant PFD*

The numbered streams in Figure 4.3 are the streams investigated and characterised throughout the pilot study. These streams will be referred to often in this dissertation and are as follows:

1. *Influent (see figures 4.2.1 and 4.2.2)*
2. *Effluent (see figures 4.2.1, 4.2.2 and 4.3)*
3. *Effluent$_{200\mu m}$*
4. *UF feed*
5. *UF permeate*
6. *RO feed*
7. *RO permeate*

The equipment and operation of the ultrafiltration and reverse osmosis systems are now discussed in more detail.

4.3.1 Ultrafiltration

4.3.1.1 Equipment and Operation

The initial focus of the study was on the RO unit and determining whether extreme fouling due to some unknown foulant in the abalone effluent sea water may occur. The UF unit was therefore initially operated with the main purpose of producing permeate to the RO unit. The focus shifted toward the UF performance as the project developed and no extreme fouling was observed on the RO membrane.

Table 4.3.1.1.1 summarises typical operating parameters for sea water UF units. The operating ranges specified here are supported by studies found in literature. It is important to remember that these operating parameters are site specific and that these ranges were only used as guideline for the start-up conditions of the UF unit in die SWRO desalination pilot study. The parameters were changed and adapted as the project developed and on-site experience was gained.

Table 4.3.1.1.1 *– Typical ultrafiltration operating parameter ranges from literature*

PARAMETER	RANGE	REFERENCE
Flux	*50 – 100 litre/m^2/h*	*(Zhang et al. 2006; Zhang et al. 2006; Bu-Rashid & Czolkoss 2007)*
Recovery	*70 – 80 %*	*(Zhang et al. 2006; Zhang et al. 2006; Bu-Rashid & Czolkoss 2007)*
Flocculation (Fe^{3+})	*3 mg/litre*	*(Jeong et al. 2011)*
CEB (intervals)	*18 – 24 hours*	*(DOW 2012)*

Inge Dizzer® P4040-6.0 ultrafiltration elements with Multibore® membranes (0.9 mm bore size, 6 m^2 surface area) and average molecular weight cut-off of 150 000 Daltons (~0.1 µm pore size) were used in the study. The fibre composition of these membranes is polyethersulfone with special additives (PESM), a hydrophilic material that resists organic fouling. The first membrane (membrane A) was used for a period of three months and the second membrane (membrane B) for a period of two months respectively. For the technical specifications of this specific module, see Appendix D. The membranes are operated in a dead-end inside-out filtration mode. Here all feed water is pushed through the membrane and concentrate is taken out of the system only during backwash sequences. The detailed process and instrumentation diagram (P&ID) and photographs of the ultra-filtration unit of the SWRO desalination pilot plant are shown in Appendix B.

The UF unit pilot study forming part of the SWRO desalination pilot plant study was divided into three experimental periods with one UF membrane (element A) and two experimental periods with the other UF membrane (element B).

The first UF membrane was operated at a range of fluxes between 25 and 100 with an average recovery of 70% with and without flocculation (3 mg/litre as Fe^{3+}). The second UF membrane is operated at fluxes ranging between 20 and 60LMH with an average recovery of 70% also with and without flocculation (3 mg/litre as Fe^{3+}). The filtration cycle lengths ranged from 720 to 1500 seconds while the backwash cycles ranged between 40 and 80 seconds. UF recovery was not optimised. In most cases, the abalone farm effluent flow rates would be significantly higher than UF feed requirements and therefore UF can be operated at lower recoveries than when the UF feed is limited.

Table 4.3.1.1.2 summarises the initial starting parameters for the different experimental periods for the ultrafiltration unit. These values are the averages of the parameter values as measured on the day of start-up before and after CEB. It is important to note that these values do change during each period; these changes are discussed in detail in the chapter 5 of this dissertation.

Table 4.3.1.1.2 *– UF start-up parameters for different experimental periods*

	Element A			Element B	
PARAMETER	**8/02/2012 - 13/03/2012**	**20/03/2012 - 03/04/2012**	**17/04/2012 - 17/05/2012**	**22/05/2012 - 15/06/2012**	**19/06/2012 - 09/07/2012**
Recovery (%)	*81*	*78*	*66*	*80*	*71*
Permeate Flux (LMH)	*79*	*83*	*40*	*60*	*29*
Backwash Flux (LMH)	*333*	*258*	*387*	*360*	*286*
Filter Duration(s)	*720*	*900*	*1500*	*1200*	*1200*
Backwash Duration (s)	*40*	*80*	*80*	*50*	*50*
CEB Interval (h)	*24*	*24*	*24*	*24*	*24*
Flocculation (mg/litre)	*3*	*0*	*0*	*0*	*3*

4.3.1.2 Ultrafiltration Membrane Cleaning and Sanitisation (CEB and CIP)

Ultrafiltration membrane cleaning and sanitisation are discussed in detail in Chapter 3 section 3.5.5 of this dissertation. For the purposes of this pilot study a CEB with NaOH and 50 mg/litre NaOCl solution at pH 12 followed by a $C_6H_8O_7$ (citric acid) solution at pH 2.5 or 1.0% (w) was used to perform backwashing once every 24 hours – except over weekends when access to the plant was limited. SMBS was applied at a concentration 3 mg/litre of SMBS per 1 mg/litre of free chlorine (Fritzmann *et al.* 2007).

The solutions used during the UF CIP of element A were selected from Table 3.5.5.2. These solutions and the types of foulants that they targeted were as follows:

- **Solution 1:** A high pH cleaning solution (target pH of 10) of 2.0% (w) of STPP (sodium tri-polyphosphate) ($Na_5P_3O_{10}$) and 0.8% (w) of Na-EDTA (sodium salt

EDTA). This is specifically recommended for removing calcium sulphate scale as well as light to moderate levels of organic foulants of natural origin. STPP functions as an inorganic-based chelating agent and detergent. Na-EDTA is an organic-based chelating cleaning agent that aids in the isolating and removal of divalent and trivalent cations and metal ions.

- **Solution 2:** A low pH cleaning solution of 2.0% (w) citric acid ($C_6H_8O_7$). It is useful in removing inorganic scale and metal oxides/hydroxides, and inorganic-based colloidal material.

- **Solution 3:** A lower pH cleaning solution (natural pH is between pH 4 and 6) 1.0% (w) of $Na_2S_2O_4$ (sodium hydrosulphite). It is useful in the removal of metal oxides and hydroxides (especially iron fouling). Sodium hydrosulphite is a strong reducing agent and is also known as sodium dithionite.

4.3.2 Reverse Osmosis

4.3.2.1 Equipment and Operation

Membrane fouling by means of scaling can be expected to occur predominantly in the last RO stages of a RO train. The last membrane in a train is also exposed to the highest concentration of solutes and therefore also the highest pressure. A ‘feed-and-bleed’ RO system was used to simulate this final membrane by recycling part of the brine to the feed stream. This type of RO system, especially one with a small capacity as used in this study, is known to be sensitive to small changes in operating parameters. It takes time to stabilise if any slight changes occur. Despite operational difficulties it produces good results with respect to the performance of RO membranes in the final stages of a RO train.

Figure 4.3.2 shows a schematic diagram of the RO unit of the SWRO desalination pilot plant setup. The same stream numbers from Figure 4.3 are used here. The detailed P&ID and photographs of the RO unit can be seen in Appendix B. A single DOW FILMTEC™ SW30-2540 (2.5 inch) Polyamide Thin-Film Composite RO membrane was used for the entire duration of the study and detailed technical specifications for this membrane are presented in Appendix D.

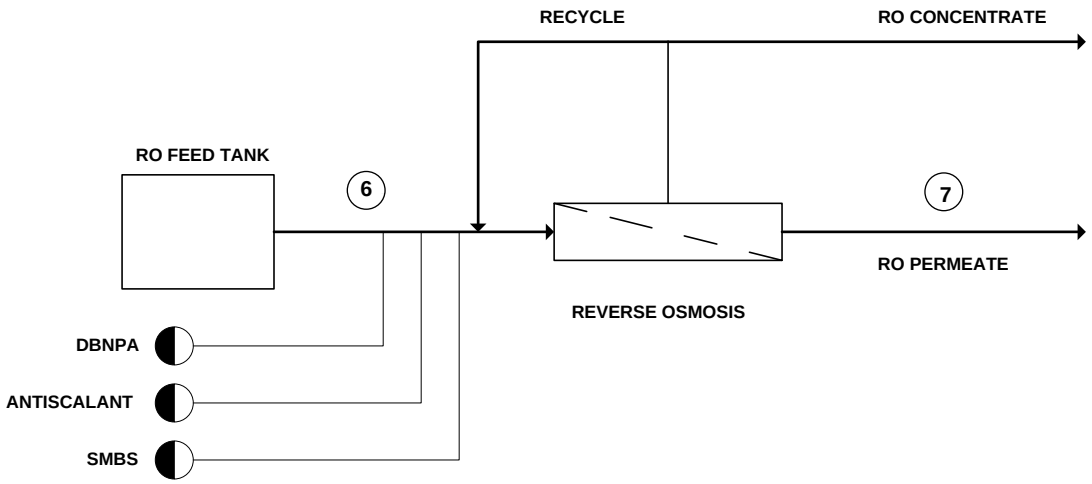

Figure 4.3.2 *– SWRO desalination pilot plant: RO 'feed-and-bleed' system*

The SWRO desalination plant was designed and built mostly from equipment that was already available to save time and costs. The capacity of the plant was therefore largely governed by the size of the available equipment. Table 4.3.2 summarises the initial start-up operating parameters for the different experimental periods for the reverse osmosis unit. These values are the parameter values as measured on the day of start-up at the beginning of each new experimental period. It is important to note that these values do change during each period; these changes are discussed in detail in Chapter 5 of this dissertation.

Table 4.3.2 *– RO start-up parameters for different experimental periods*

PARAMETER	17/02/2012 - 13/03/2012	20/03/2012 - 03/04/2012	17/04/2012 - 17/05/2012	24/05/2012 - 02/07/2012	04/07/2012 - 09/07/2012
Feed Pressure (bar)	*56.5*	*57.0*	*58.0*	*59.0*	*60.0*
Recovery Single Pass (%)	*8.0*	*8.1*	*8.1*	*8.2*	*8.2*
Recovery Overall (%)	*42.4*	*42.4*	*42.4*	*43.1*	*43.9*
Permeate Flux (LMH)	*8.9*	*8.9*	*8.9*	*9.2*	*9.0*
Feed (litre/h)	*59.0*	*59.0*	*59.0*	*59.9*	*57.7*
Permeate (litre/h)	*25.0*	*25.0*	*25.0*	*25.8*	*25.3*
Concentrate (litre/h)	*34.0*	*34.0*	*34.0*	*34.1*	*32.4*
Recycle (litre/h)	*255.1*	*249.6*	*249.6*	*254.7*	*250.9*
Antiscalant (mg/litre)	*12*	*12*	*12*	*11*	*11*
DBNPA (mg/litre weekly)	*30*	*30*	*30*	*30*	*30*

The RO feed water pH is not adjusted and range between pH 6 and 8 with a mean value of pH 7.5. Antiscalants were dosed to give a concentration in the concentrate stream of 20 mg/litre as per recommendation by suppliers. For example, the dosage in the feed stream of a system with 45% recovery is 11 mg/litre. Antiscalants, Flocon 260 (10 mg/litre), and Hydrex4101 (10 mg/litre) were respectively dosed during RO treatment. DBNPA was dosed once every week at a rate of 10 – 30 mg/litre for 30 minutes up to 3 hours to prevent biofouling. Single pass water recovery was kept at approximately 7.9 – 8.3% or an overall

recovery of 40.0 – 43.5%. These recoveries are within the boundaries specified by the membrane supplier for sea water desalination (DOW 2012). The RO permeate flux was measured as a function of time while the chemical composition and turbidity of the RO feed, permeate and concentrate were also determined.

4.3.2.2 Reverse Osmosis Membrane Cleaning and Sanitisation (CIP)

The solutions used during CIP_1 and CIP_3 of the RO membrane were the same solutions used for the CIP of the UF membrane. For CIP_2 of the RO membrane slightly different cleaning solutions were tested as follows:

- **Solution 1:** This is a high pH cleaning solution; 0.1% (w) of NaOH (pH 11.5, 35°C maximum).

- **Solution 2:** This is a low pH cleaning solution of 0.2% (w) HCl (pH 1 – 2, 25°C maximum).

4.3.3 SWRO Desalination Pilot Plant Data Sampling

Data sampling for the UF part of the pilot plant was done in the morning before and after the CEB was completed. Flow rates, trans-membrane pressure, temperature, conductivity, TDS, salinity and pH readings were therefore taken twice every day, except during weekends. Turbidity readings are taken once a day. Data sampling for the reverse osmosis part of the pilot plant system was also done twice daily; once in the morning after the CEB for the UF has been performed and once in the afternoon. Flow rates, pressure, temperature, conductivity, TDS, salinity and pH readings are taken twice every day, except during weekends. Turbidity readings are taken at least three times a week. Table 4.3.3.1 summarises the data sampling done on-site during the pilot study.

Water samples from the UF permeate and RO permeate streams from the pilot plant were also sent for analysis to the Council for Scientific and Industrial Research (CSIR) at their ISO17025 accredited laboratories in Stellenbosch. Table 4.3.3.2 is a summary of the water characterisation parameters analysed by the CSIR laboratories.

Table 4.3.3.1 *– SWRO desalination pilot plant on-site data sampling*

PARAMETER/INTRUMENT	UNITS	PERIOD	FREQUENCY	COMMENTS
Flow Rate (stopwatch and measuring beaker)				
UF Feed	*litre/h*	*17/02/2012 - 9/07/2012*	*2 times/ day*	*Flow rates measured before and after CEB*
UF Backwash	*litre/h*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
UF Permeate	*litre/h*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
RO Feed	*litre/h*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
RO Concentrate	*litre/h*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
RO Permeate	*litre/h*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
Pressure (pressure gauges)				
UF Permeate TMP	*kPa*	*17/02/2012 - 9/07/2012*	*2 times/ day*	*Pressures measured before and after CEB*
UF Backwash TMP	*kPa*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
RO Feed Pressure	*bar*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
RO Brine Pressure	*bar*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
YSI Professional Plus Multi-meter				
Temperature	*°C*	*17/02/2012 - 9/07/2012*	*2 times/ day*	*Measured before and after CEB*
Conductivity	*µS/cm*	*17/02/2012 - 9/07/2012*	*2 times/ day*	*UF feed and UF permeate streams analysed*
Specific Conductivity	*µS/cm*	*17/02/2012 - 9/07/2012*	*2 times/ day*	*RO feed, RO concentrate and RO permeate streams analysed*
Total Dissolved Solids (TDS)	*mg/litre*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
Dissolved Oxygen (DO)	*mg/litre*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
pH	*-*	*17/02/2012 - 9/07/2012*	*2 times/ day*	
HANNA HI98703 Turbidity Meter				
Turbidity	*NTU*	*17/02/2012 - 9/07/2012*	*3 times/week*	*Measured after CEB* *UF feed and UF permeate streams analysed* *RO permeate stream analysed*

Table 4.3.3.2 *– SWRO pilot plant stream parameters analysed by the CSIR laboratories*

PARAMETER	UNITS	SAMPLING DATES
Physical and organoleptic requirements		
Specific Conductivity	*µS/cm*	*30/04/2012; 9,25/06/2012*
pH		*30/04/2012; 9,25/06/2012*
Total Dissolved Solids (TDS)	*mg/litre*	*30/04/2012; 9,25/06/2012*
Macro Determinants		
Cations and Anion Balance	*-*	*30/04/2012; 9,25/06/2012*
Potassium as K	*mg/litre*	*30/04/2012; 9,25/06/2012*
Sodium as Na	*mg/litre*	*30/04/2012; 9,25/06/2012*
Calcium as Ca	*mg/litre*	*30/04/2012; 9,25/06/2012*
Magnesium as Mg	*mg/litre*	*30/04/2012; 9,25/06/2012*
Ammonia as N	*mg/litre*	*30/04/2012; 9,25/06/2012*
Sulphate as SO4	*mg/litre*	*30/04/2012; 9,25/06/2012*
Chloride Cl	*mg/litre*	*30/04/2012; 9,25/06/2012*
Alkalinity as CaCO3	*mg/litre*	*30/04/2012; 9,25/06/2012*
Fluoride as F	*mg/litre*	*30/04/2012; 9,25/06/2012*
Nutrients		
Nitrate plus Nitrite as N	*mg/litre*	*30/04/2012; 9,25/06/2012*
Nitrate as NO3	*mg/litre*	*30/04/2012; 9,25/06/2012*
Nitrite as NO2	*mg/litre*	*30/04/2012; 9,25/06/2012*
Ortho phosphate as P	*mg/litre*	*30/04/2012; 9,25/06/2012*
Dissolved Organic Carbon (DOC)	*mg/litre*	*30/04/2012; 9,25/06/2012*
Kjeldahl Nitrogen as N	*mg/litre*	*30/04/2012; 9,25/06/2012*
Metals		
Boron as B Dissolved	*mg/litre*	*30/04/2012; 9,25/06/2012*
Silica as Si Dissolved	*mg/litre*	*30/04/2012; 9,25/06/2012*
Strontium as Sr Dissolved	*mg/litre*	*30/04/2012; 9,25/06/2012*
Bomide as Br Dissolved	*mg/litre*	*30/04/2012; 9,25/06/2012*
Iron as Fe Dissolved	*mg/litre*	*30/04/2012; 9,25/06/2012*
Manganese as Mn Dissolved	*mg/litre*	*30/04/2012; 9,25/06/2012*

4.3.4 Total Dissolved Solids for Different Desalination Water Types

In his paper Walton (1989) demonstrates the considerable problems, both theoretical and practical, associated with applying just one simple linear conversion factor between conductivity and TDS throughout the range of waters encountered in the desalination industry. He suggested that several different conversion factors ranging from 0.50 to 0.75 needs to be used for increasingly saline waters. However, since most desalination plants utilise fairly predictable water types with regards to its conductivity, the conversion factors

can be approximated in advance. The conversion factors that he suggested and that were used through pilot plant study are presented in Table 4.3.4.

Table 4.3.4 *- Suggested conductivity to TDS conversion factors for use with different desalination water types (Walton 1989)*

WATER TYPE	SPECIFIC CONDUCTANCE (µS/cm)	CONVERSION FACTOR
Distillate	*1 – 10*	*0.50*
RO permeate	*300 – 800*	*0.55*
Sea water	*45 000 – 60 000*	*0.70*
RO Concentrate	*65 000 – 85 000*	*0.75*

4.4 ON-SITE EXPERIENCE

What was learnt on-site in terms of incidents which could have an effect on the performance of the water desalination pilot plant was continuously noted and logged throughout the time spent on the farm. Attention was also given to the general management on the farm focusing specifically on identifying possible problem areas regarding the integration of a desalination plant with the abalone farm. This was done over the entire twelve month period (July 2011 to July 2012) spent on the farm. The problems identified include major natural effects (such as ocean currents, seasonal changes, red tide etc.) as well as human effects (such as power failures, tank cleaning schedules, animal sorting schedules *etcetera*). These lessons that were learned helped to show whether it would be feasible and viable to integrate an SWRO desalination plant with a typical South African abalone farm.

4.5 COSTING STUDY

The cost implications related to the integration of an SWRO plant with an abalone farm was done in three parts. In the first part literature pertaining to the cost of SWRO desalination and more specifically intake systems was reviewed. In the second part the expected UPC of desalinated water was determined from available literature sources. Finally typical cost breakdown structures were investigated to determine the percentage contribution of intake systems to the desalinated UPC water.

CHAPTER 5

5. RESULTS AND DISCUSSION

"If there is magic on this planet, it is contained in water."
- LORAN EISELY, The Immense Journey, 1957

Now that the research design and methodology have been outlined the results for the study are presented and discussed. The water characterisation of the abalone tanks and combined streams are dealt with first and then followed by a discussion of the pilot study results.

5.1 WATER CHARACTERISATION: INDIVIDUAL ABALONE TANKS

Water characterisation parameters of the individual abalone tanks were measured over a period of almost 7 months from 19 October 2011 to 26 April 2012 to establish the effect of abalone tank systems on the sea water flowing through. The effect of seasonal changes on the sea water influent and effluent streams were also investigated.

5.1.1 Temperature

Figure 5.1.1 presents the mean temperature values for the forty individual abalone tanks investigated. The bars indicate the standard deviation in temperature between the individual tanks. The reader is referred to Appendix C for the temperature data pertaining to all the individual tanks.

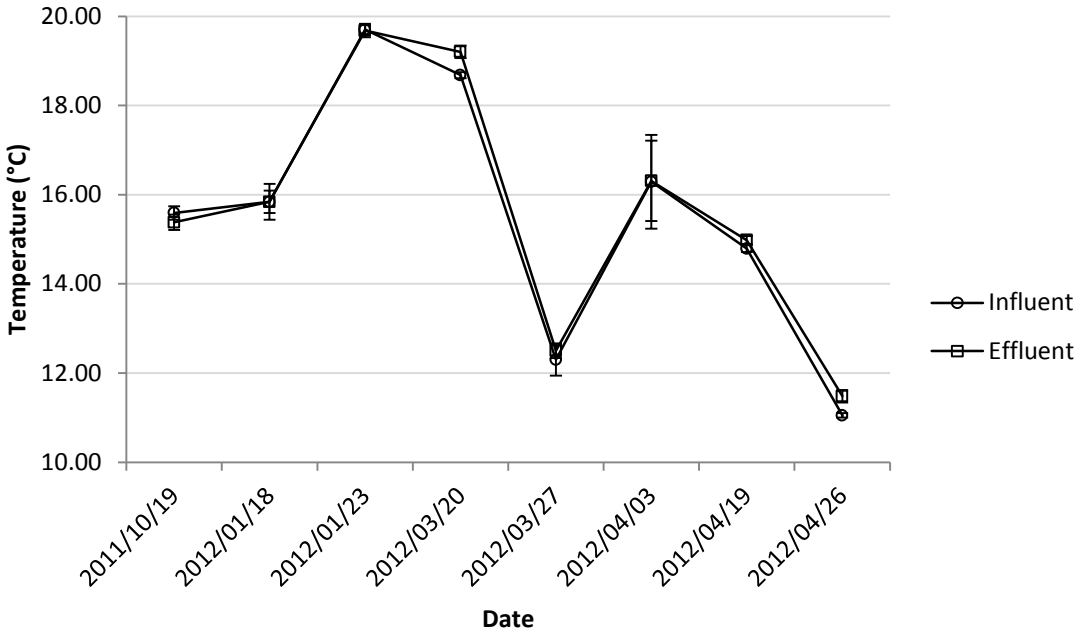

Figure 5.1.1 *– Abalone tank influent and effluent stream mean temperature*

A few important observations can be made from the graph shown in Figure 5.1.1. The bars showing the standard deviation in influent and effluent temperature between the individual tanks for each respective sampling date are small. This shows that there was little difference between individual tanks with regards to its influence on water temperature. It was therefore correct to assume that the forty tanks in the designated area could adequately represent the tanks from the entire farm with respect to its influence on temperature.

Table 5.1.1 summarises the overall temperature statistics as measured throughout the entire seven month period. The difference between the tank inlet and outlet water temperature is insignificant (1% increase). The seasonal temperature difference is quite high with temperatures of approximately 15°C in spring (October – January) going up to almost 20°C in summer (January – March) and back down to about 11.0°C in autumn (March – April). These temperature changes can however be ascribed to weather and oceanic conditions and is unaffected by the abalone tanks. From Table 5.1.1 the minimum and maximum temperatures over this period are 11.0°C and 19.8°C respectively, with a mean temperature of 15.5°. However, the modal temperature was 11.0°C.

Table 5.1.1 *– Abalone tank influent and effluent stream temperature statistics*

TEMPERATURE (°C)	IN	OUT	OUT-IN (°C)	(OUT-IN)/IN (%)
Mean	*15.5*	*15.6*	*0.1*	*1.1*
Median	*15.5*	*15.5*	*0.0*	*0.0*
Mode	*11.0*	*15.5*	*0.3*	*0.0*
Standard Deviation	*2.7*	*2.7*	*0.3*	*2.1*
Sample Variance	*7.4*	*7.1*	*0.1*	*4.4*
Kurtosis	*-0.94*	*-0.99*	*-0.33*	*-0.34*
Skewness	*-0.10*	*0.04*	*-0.27*	*-0.02*
Range	*8.8*	*8.6*	*1.5*	*11.3*
Minimum	*11.0*	*11.3*	*-0.7*	*-4.07*
Maximum	*19.8*	*19.9*	*0.8*	*7.21*
Confidence Level (95.0%)	*0.3*	*0.3*	*0.0*	*0.0*

An increase in water temperature increases both permeate water flow rate and salt flow rate and should therefore not affect permeate salinity. It will however decrease the viscosity of the water, requiring lower feed pressures to maintain the same flux which then results in an increase in permeate salinity (if the flux remains the same).

5.1.2 Specific Conductivity

Figure 5.1.2 presents the mean specific conductivity (µS/cm at 25°C) values for the forty individual abalone tanks investigated. The bars indicate the standard deviation in specific conductivity between the individual tanks. For the data pertaining to the specific conductivities as measured for each individual tank the reader is referred to Appendix C.

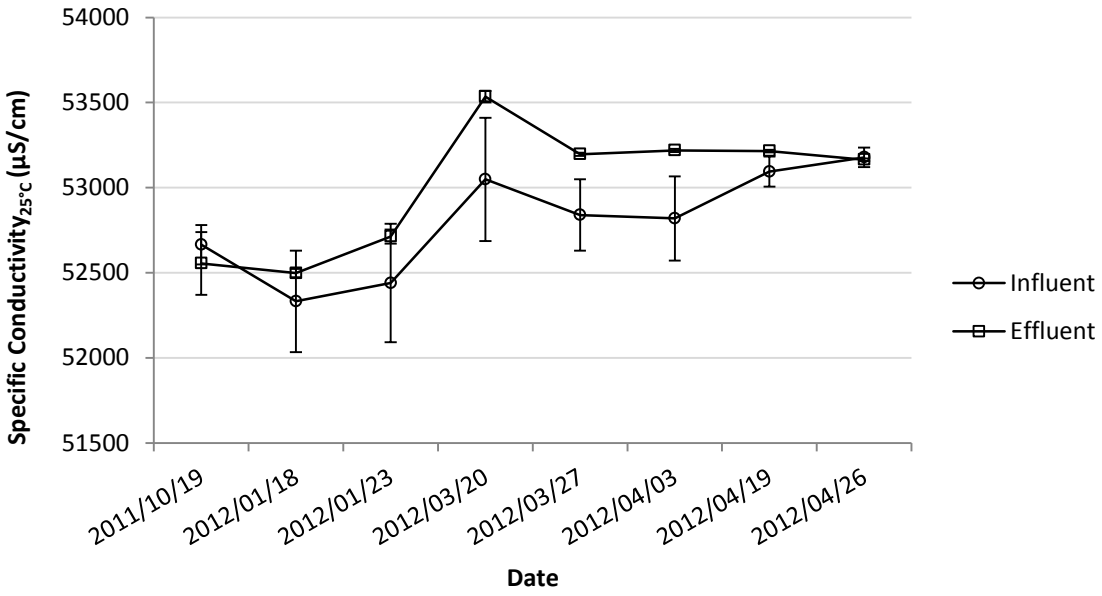

Figure 5.1.2 *– Abalone tank influent and effluent stream mean specific conductivity*

From Figure 5.1.2 the abalone tanks did not seem to have a significant effect on the specific conductivity of the water, as was expected. However for most of the time the conductivity of the effluent seemed to be slightly higher than that of the influent. There was a slight step increase in conductivity during March which was caused by changes in oceanic conditions. The bars indicate the standard deviation in specific conductivity between the individual tanks as measured on each respective sampling date. The deviation in specific conductivity between the tanks was larger for the influent stream than that for the effluent stream. However, both the inlet and outlet specific conductivities from these forty tanks should be able to adequately represent that of the entire farm.

The overall descriptive statistics for the specific conductivity of all forty tanks as measured throughout the entire seven month period are summarised in Table 5.1.2.

Table 5.1.2 *– Abalone tank influent and effluent stream specific conductivity statistics*

SPECIFIC CONDUCTIVITY (µS/cm)	IN	OUT	OUT-IN (µS/cm)	(OUT-IN)/IN (%)
Mean	*52 784*	*53011*	*227*	*0.4*
Median	*52 853*	*53 181*	*130*	*0.2*
Mode	*52 720*	*53 215*	*126*	*#N/A*
Standard Deviation	*426*	*366*	*354*	*0.7*
Sample Variance	*181 480*	*133 727*	*125 649*	*0.5*
Kurtosis	*9.7*	*-1.1*	*8.9*	*10.0*
Skewness	*-2.2*	*-0.4*	*2.2*	*2.4*
Range	*3 448*	*1 471*	*2 904*	*5.8*
Minimum	*50 034*	*52 185*	*-475*	*-0.9*
Maximum	*53 482*	*53 656*	*2429*	*4.9*
Confidence Level (95.0%)	*47.4*	*40.7*	*39.4*	*0.1*

The instrument accuracy for measuring conductivity is ±0.5% of the reading or 0.001 mS/cm, whichever is greater, when using a 4m cable as done in this study. The mean increase in specific conductivity of 227 µS/cm (or 0.4%) is therefore not significant since it is less than the accuracy range for the instrument. The specific conductivity ranged between 50 034 µS/cm and 53 656 µS/cm with mean values of 52 783 µS/cm and 53 011 µS/cm for the influent and effluent respectively.

5.1.3 Total Dissolved Solids

Figure 5.1.3 presents the mean TDS values derived from specific conductivity measurements for the forty individual abalone tanks investigated. The bars indicate the standard deviation in TDS between the individual tanks as measured on each respective sampling date. For the TDS data pertaining to each individual tank the reader is referred to Appendix C.

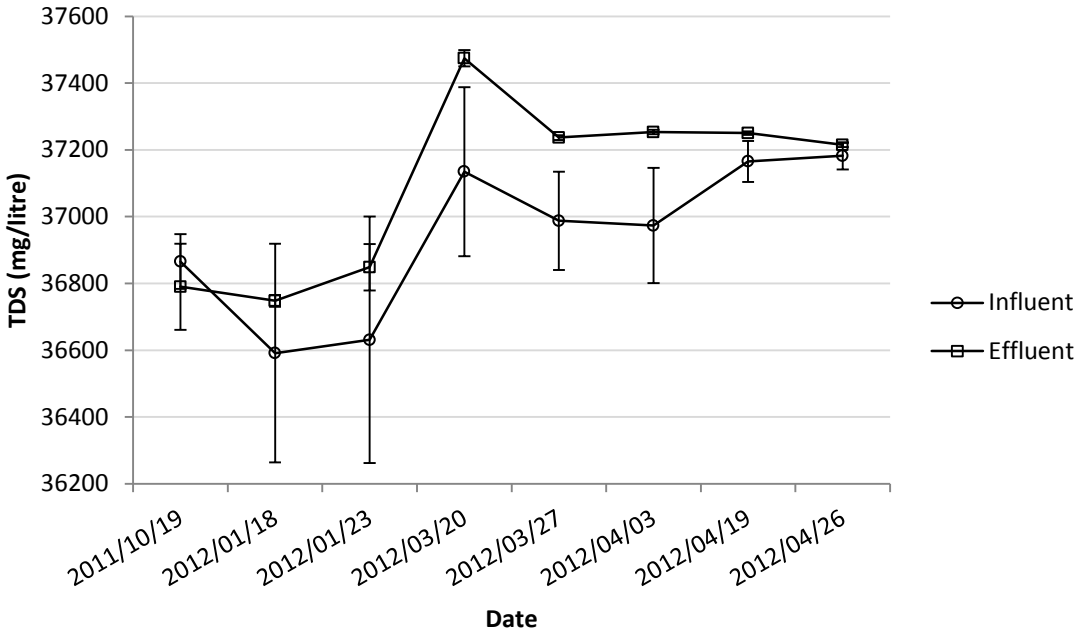

Figure 5.1.3 *– Abalone tank influent and effluent stream mean TDS (based on conductivity)*

The overall descriptive statistics for all the tanks investigated are summarised in Table 5.1.3.

Table 5.1.3 *– Abalone tank influent and effluent stream TDS statistics*

TDS (mg/litre)	IN	OUT	OUT-IN (mg/litre)	(OUT-IN)/IN (%)
Mean	*36948*	*37108*	*159*	*0.4*
Median	*36995*	*37226*	*91*	*0.2*
Mode	*37212*	*37247*	*0*	*0.0*
Standard Deviation	*298*	*256*	*248*	*0.7*
Sample Variance	*88961*	*65486*	*61506*	*0.5*
Kurtosis	*9.7*	*-1.1*	*8.9*	*10.1*
Skewness	*-2.2*	*-0.4*	*2.2*	*2.4*
Range	*2415*	*1029*	*2030*	*5.7*
Minimum	*35021*	*36533*	*-329*	*-0.9*
Maximum	*37436*	*37562*	*1701*	*4.9*
Sum	*11564826*	*11614694*	*49868*	*136.0*
Confidence Level (95.0%)	*33.2*	*28.5*	*27.6*	*0.1*

Influent TDS ranged between 35 012 and 37 436 mg/litre with a mean value of 36948 mg/litre. Effluent TDS ranged between 36 533 and 37 562 mg/litre with a mean value of 37 226 (0.4% increase from that of the influent stream). The TDS results are similar to that of the specific conductivity since it is directly derived from it. The TDS results for all forty tanks are shown in Appendix C.

5.1.4 Salinity

An increase in feed conductivity (or salinity or TDS) decreases permeate flow rate (due to increased osmotic pressure difference), increases permeate salt flow (due to increased concentration difference) and therefore increases permeate salinity. It should also be noted that any change in the feed conductivity to the SWRO pilot plant will be magnified by the 'feed-and-bleed' RO system used in the pilot study.

Figure 5.1.4 presents the mean salinity for the forty individual abalone tanks investigated. The bars indicate the standard deviation in salinity between the individual tanks as measured on each respective sampling date. The results for all the tanks are similar and are shown in Appendix C. There is no significant change in salinity of the influent and effluent streams. A slight increase in salinity is observed during the month of March, corresponding to decreased water temperature during this time.

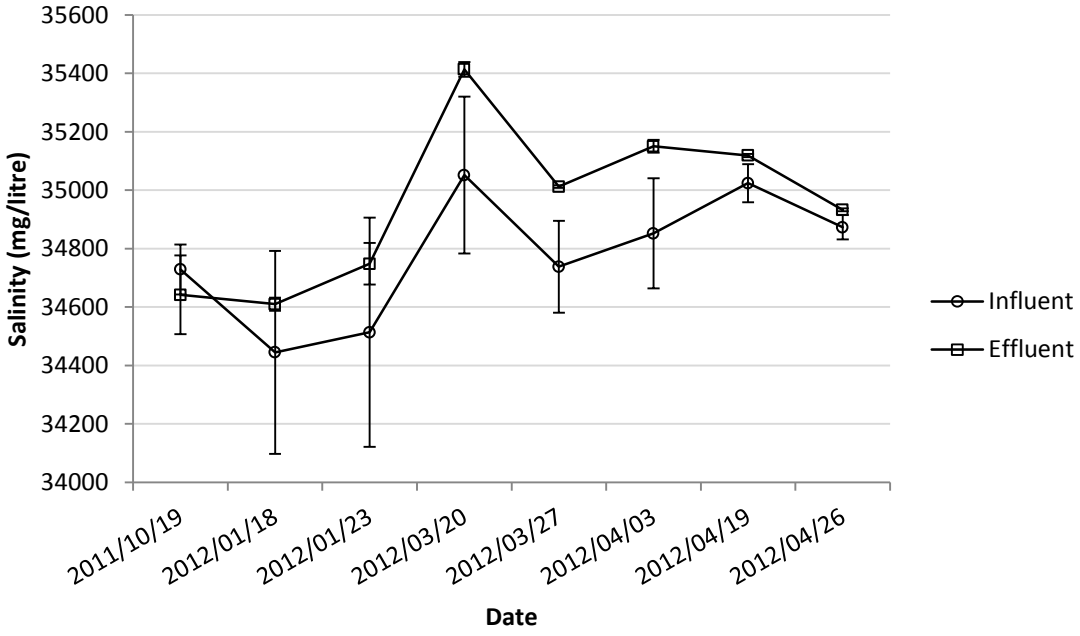

Figure 5.1.4 *– Abalone tank influent and effluent stream mean salinity (based on conductivity)*

Table 5.1.4 is a summary of the descriptive statistics for the salinity as measured for all the tanks over the 7 month period. The salinity ranged between 32 790 and 35 370 mg/litre and has mean values of 34 785 and 34 958 mg/litre (that amounts to a 173 mg/litre or 0.5% increase) for the influent and effluent streams respectively. This increase is below the accuracy range of the instrument and therefore insignificant.

Table 5.1.4 *– Abalone tank influent and effluent stream salinity statistics*

SALINITY (mg/litre)	IN	OUT	OUT-IN (mg/litre)	(OUT-IN)/IN (%)
Mean	*34785*	*34958*	*173*	*0.5*
Median	*34800*	*35010*	*100*	*0.3*
Mode	*34740*	*35120*	*50*	*0.0*
Standard Deviation	*299*	*266*	*262*	*0.8*
Sample Variance	*89665*	*70948*	*68556*	*0.6*
Kurtosis	*11*	*-1*	*9*	*10.0*
Skewness	*-2*	*0*	*2*	*2.3*
Range	*2580*	*1140*	*2150*	*6.5*
Minimum	*32790*	*34360*	*-360*	*-1.0*
Maximum	*35370*	*35500*	*1790*	*5.5*
Sum	*10887610*	*10941910*	*54300*	*157.3*
Confidence Level (95.0%)	*33.3*	*29.6*	*29.1*	*0.1*

5.1.5 Dissolved Oxygen

Figure 5.1.5 presents the mean dissolved oxygen levels for the forty individual abalone tanks investigated. Standard deviation bars indicate the standard deviation in salinity between the individual tanks as measured on each respective sampling date. The results for dissolved oxygen levels for all forty tanks are similar to the graph presented here and are shown in Appendix C.

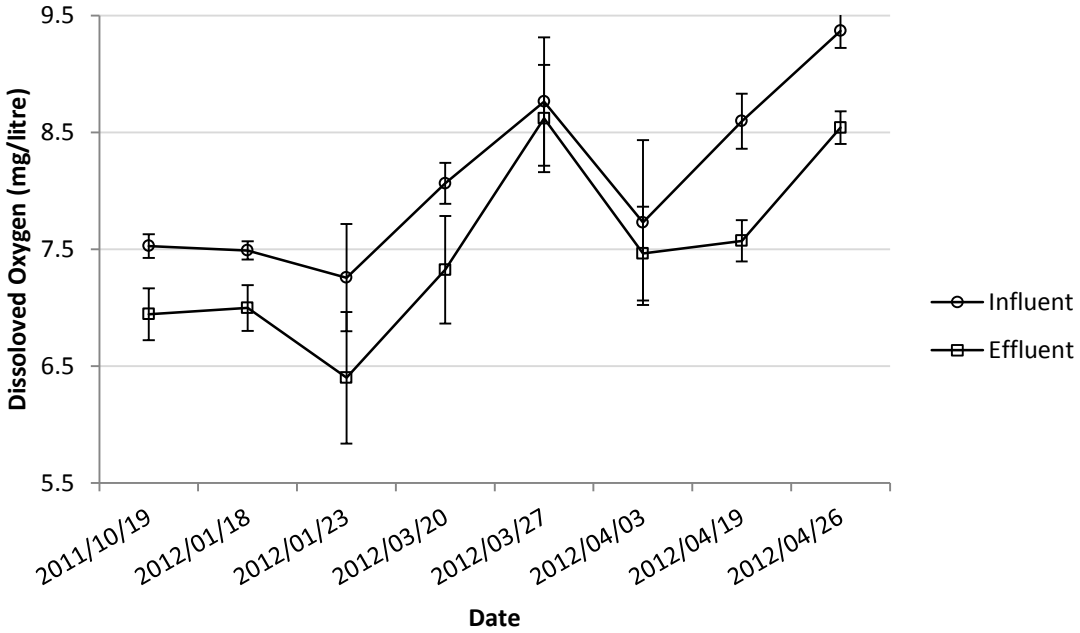

Figure 5.1.5 *– Abalone tank influent and effluent stream mean dissolved oxygen levels*

The overall descriptive statistics for the influent and effluent streams DO concentration measured throughout the seven month period are summarised in Table 5.1.5.

Table 5.1.5 *– Abalone tank influent and effluent stream dissolved oxygen statistics*

DISSOLVED OXYGEN (mg/litre)	IN	OUT	OUT-IN (µS/cm)	(OUT-IN)/IN (%)
Mean	*8.1*	*7.5*	*-0.6*	*-7.5*
Median	*8.0*	*7.4*	*-0.7*	*-8.0*
Mode	*7.5*	*7.0*	*-0.8*	*-6.5*
Standard Deviation	*0.8*	*0.8*	*0.5*	*6.7*
Sample Variance	*0.6*	*0.7*	*0.3*	*44.2*
Kurtosis	*-1.0*	*-0.7*	*1.1*	*1.2*
Skewness	*0.3*	*0.2*	*0.3*	*0.6*
Range	*3.3*	*3.4*	*3.7*	*46.9*
Minimum	*6.4*	*5.8*	*-2.6*	*-29.8*
Maximum	*9.7*	*9.2*	*1.1*	*17.1*
Confidence Level (95.0%)	*0.1*	*0.1*	*0.1*	*0.7*

The instrument accuracy for measuring DO between 0 and 20 mg/litre is ±2% of the reading or 0.2 mg/litre. The average decrease of 0.62 mg/litre O_2 (or 7.46%) is definitely significant and it can with confidence be said that the dissolved oxygen decreases right across the individual abalone tank systems. The molluscs consume the oxygen as they eat and metabolise food. The DO levels are highly dependent on temperature and salinity (Truesdale et al. 2007; Benson & Krause 1984), but the YSI Pro Plus compensates for these factors using various built-in algorithms.

Eriksson (1991) found that dissolved oxygen levels (as high as 27 mg/litre) did not have any effect on the performance of a SW30HR FILMTEC® FT30 membrane (similar to the membrane used in this study). It is therefore accepted that the change in dissolved oxygen would not affect the performance of the RO membrane in this study.

5.1.6 pH

In aquatic environments, carbon dioxide (CO_2) produced during respiration reacts with water to form a weak carbonic acid (H_2CO_3). Carbonic acid dissociates into bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and hydrogen ions (H^+). The release of hydrogen ions decreases the pH of the water (Sanni & Forsberg 1996).

Similarly, the nitrification of ammonia to nitrate by nitrifying bacteria results in the release of H^+ ions (S. Chen *et al.* 2006) often followed by a reduction in the buffering capacity of the water. Thus, in high-intensity culture systems, changes in pH are likely to occur from the

accumulation of CO_2 released by the cultured animal (Sanni & Forsberg 1996; Fivelstad *et al.* 1998; Colt *et al.* 2009) and CO_2 produced during nitrification (Colt *et al.* 2009).

The pH for the influent and effluent streams of each of the forty abalone tanks was measured with an accuracy of ±0.2 units. The mean pH values for the forty individual abalone tanks investigated are presented in Figure 5.1.6. The bars indicate the standard deviation in pH between the individual tanks as measured on each respective sampling date. The pH values measured for each individual tank are presented in Appendix C.

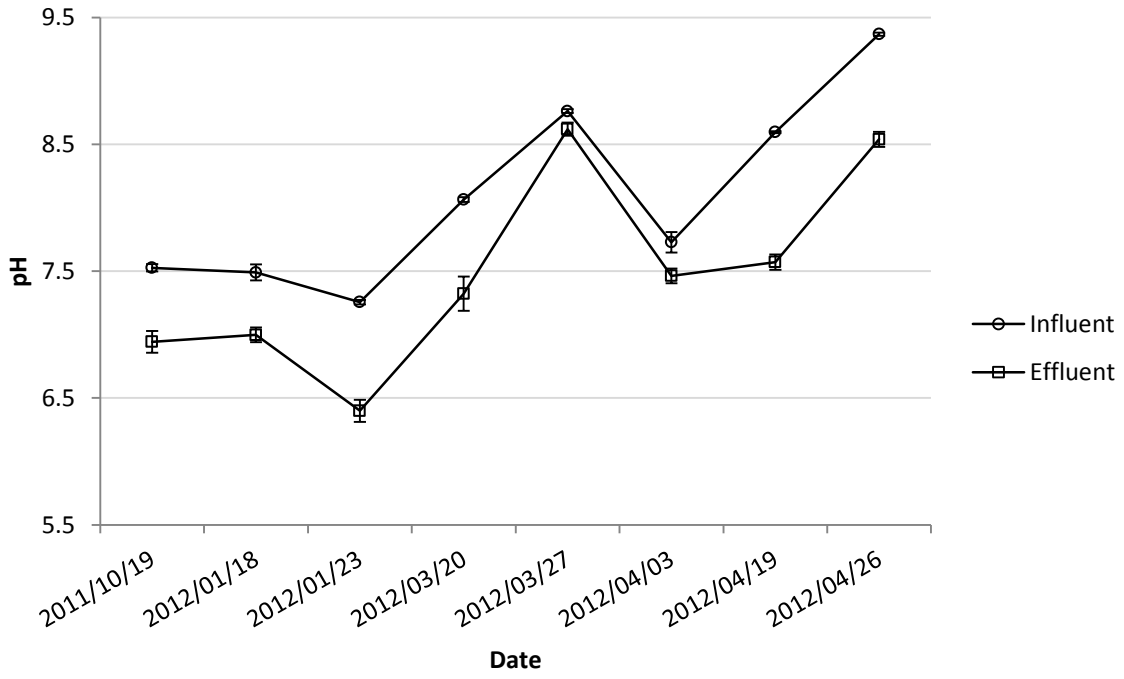

Figure 5.1.6 *– Abalone tank influent and effluent stream mean pH*

The overall descriptive statistics for the influent and effluent stream pH as measured for all of the tanks sampled are summarised in Table 5.1.6. From these statistics it can be seen that the average decrease in pH across all the abalone tanks is only 0.16 for the data available. This is less than the accuracy for the instrument (±0.2 units). The average change in pH per tank is therefore not significant although researchers such as Yearsley (Yearsley 2008) and Naylor (Naylor *et al.* 2010) also show average decreases in pH of 0.16 and 0.1 units respectively.

Table 5.1.6 *– Abalone tank influent and effluent stream pH statistics*

pH	IN	OUT	OUT-IN	(OUT-IN)/IN (%)
Mean	*8.2*	*8.0*	*-0.2*	*-2.0*
Median	*8.2*	*8.0*	*-0.2*	*-1.8*
Mode	*8.1*	*8.0*	*-0.1*	*-1.6*
Standard Deviation	*0.2*	*0.2*	*0.1*	*1.3*
Sample Variance	*0.0*	*0.0*	*0.0*	*1.6*
Kurtosis	*-0.3*	*0.2*	*-0.1*	*0.0*
Skewness	*0.4*	*0.7*	*-0.3*	*-0.3*
Range	*0.6*	*0.8*	*0.7*	*8.0*
Minimum	*7.9*	*7.6*	*-0.5*	*-6.7*
Maximum	*8.6*	*8.4*	*0.1*	*1.4*
Confidence Level (95.0%)	*0.0*	*0.0*	*0.0*	*0.1*

5.1.7 Turbidity

Influent and effluent stream turbidity for each tank was measured weekly during the seven month period mentioned. Every sample was measured three times and the average of these readings was taken as the turbidity for that specific sample. The resulting turbidity for one tank is shown in Figure 5.1.7; the turbidity readings for all the tanks sampled are shown in Appendix C.

A number of interesting observations can be made from Figure 5.1.7. The influent and effluent turbidity for the water was lower during spring/summer than during the autumn months. This was due to the seasonal changes in weather and oceanic conditions. The spike in turbidity on the 1 November was due to an algal bloom (red tide) that hit the bay from where the farm extracts its water. The intake system drum filter screens were dislocated. This resulted in an increase in water turbidity right across the farm. During the second week of February the main pipeline to the farm was ‘pigged’ for the first time in 15 years. The pipeline was ‘pigged’ in a stepwise manner which took about a week, resulting in poor quality water as debris was flushed out of the pipe. This increase in debris in the water resulted in a peak in the water turbidity during February. The increase in turbidity in March can partly be ascribed to red bait, this time breaking the drum filters as well as causing pipe blockages. Seasonal changes during this period also led to decreased inlet water quality.

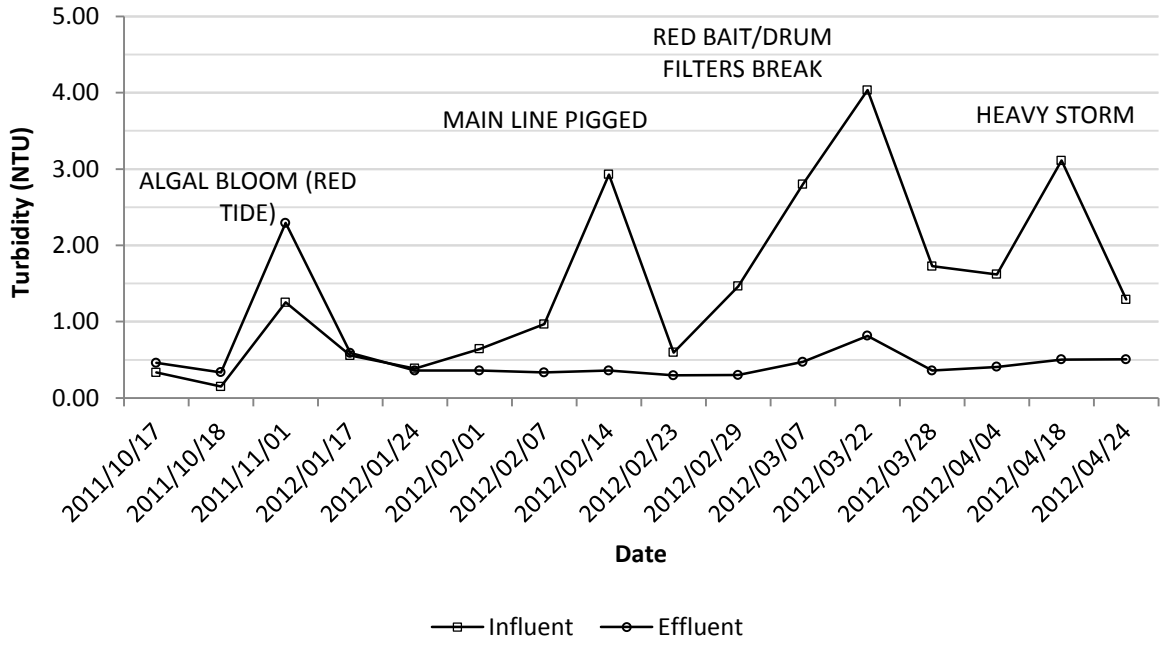

Figure 5.1.7 *– Turbidity of an individual abalone tank*

The turbidity was decreased to a value between 0 and 2.5 NTU overall, regardless of the incoming turbidity observed over the entire period measured. The tanks act as settlers/clarifiers, which retain a large part of the incoming suspended solids. The abalone baskets are made from net or mesh. Some suspended matter stick to this mesh and build up on these mesh baskets to form a 'filtration cake'. The size or density of this 'filter cake' then increases with time until the basket is washed again. The reduction in turbidity therefore shows an increase with time until the 'filter cake' is washed off again – restarting the process.

Turbidity was therefore always measured within a day of the baskets being cleaned to ensure 'worst case' readings, knowing that the retention of particles will only increase with time until the baskets are washed again. The retained particles are washed off once a week when abalone tanks are cleaned.

The overall descriptive statistics for the influent and effluent stream turbidity, as measured for all of the tanks sampled, are summarised in Table 5.1.7. From these statistics it is clear that the average decrease in turbidity across all the abalone tanks is almost 52% (from 1.06 to 0.51 NTU). The low mean effluent turbidity of 0.51 is a very good sign. Although on occasion the influent turbidity reached a value as high as 8.75 NTU the highest effluent turbidity measured was only 2.34 NTU.

Table 5.1.7 *– Abalone tank influent and effluent stream turbidity statistics*

TURBIDITY	IN	OUT	OUT-IN	(OUT-IN)/IN (%)
Mean	*1.1*	*0.5*	*-0.6*	*-51.6*
Median	*0.9*	*0.4*	*-0.5*	*-51.6*
Mode	*0.6*	*0.4*	*-0.2*	*-37.4*
Standard Deviation	*0.9*	*0.3*	*-0.5*	*-63.3*
Sample Variance	*0.7*	*0.1*	*-0.6*	*-86.5*
Kurtosis	*18.1*	*11.8*	*-6.3*	*-34.9*
Skewness	*3.1*	*3.3*	*0.2*	*4.8*
Range	*8.6*	*2.1*	*-6.5*	*-75.3*
Minimum	*0.1*	*0.2*	*0.1*	*48.8*
Maximum	*8.8*	*2.3*	*-6.4*	*-73.3*
Confidence Level (95.0%)	*0.1*	*0.0*	*0.0*	*-63.3*

From these turbidity results one would expect the lower turbidity in the abalone effluent water to place a lower load on the pre-treatment for reverse osmosis than the influent water would.

5.2 WATER CHARACTERISATION: COMBINED STREAMS

Refer to figure 4.3 for identification of “combined” streams. The results obtained from laboratory analyses showing, the typical composition of the feed and effluent streams, are summarised in Table 5.2.1. Water samples were taken on the 30 March 2012, 9 June 2012 and 25 June 2012 and sent for analysis at the CSIR laboratories in Stellenbosch (as described in section 4.2.4 of this dissertation).

The composition of the influent is typical of Atlantic sea water (El-Dessouky & Ettouney 2002). Overall the abalone tanks do not have any significant effect on the chemical composition of the sea water. The DOC – an indicator of organic matter – of both the influent and effluent streams was always below 1 mg/litre indicating that flocculation may not be required as part of pre-treatment for RO.

Water characterisation parameters of the combined streams were measured over a period of almost four months from 20 March 2012 to 9 July 2012 as described in section 4.2.4 of this dissertation. Table 5.2.2 presents a summary of the descriptive statistics of the results found for all parameters measured on-site during this period. Table 5.2.2 is followed by a discussion on the trends observed for each parameter.

When considering these results it is important to note that the RO ‘feed-and-bleed’ pilot plant simulated the behaviour of the *last* membrane in a full-scale RO membrane bank. Furthermore, potabilisation of the RO permeate was not performed as part of this study.

Therefore, the RO permeate from the pilot plant did not adhere to the SANS 241:2011 drinking water standards (SABS Standards Division, 2011). However, the quality of this permeate was fully on par with the quality expected from permeate produced by the last membrane in a full-scale membrane bank.

Table 5.2.1 *– Influent and effluent water composition (CSIR laboratory analyses)*

		INFLUENT			EFFLUENT		
COMPONENT	**UNITS**	**MIN**	**MAX**	**MEAN**	**MIN**	**MAX**	**MEAN**
Potassium as K	*mg/litre*	*365*	*435*	*389*	*362*	*580*	*444*
Sodium as Na	*mg/litre*	*10 901*	*11 165*	*11 010*	*10 815*	*13 754*	*11 880*
Calcium as Ca	*mg/litre*	*394*	*439*	*418*	*425*	*647*	*500*
Magnesium as Mg	*mg/litre*	*1 263*	*1 307*	*1 288*	*1 209*	*1 692*	*1 391*
Ammonia as N	*mg/litre*	*0.024*	*0.037*	*0.029*	*0.032*	*0.053*	*0.044*
Sulphate as SO_4	*mg/litre*	*2 922*	*2 970*	*2 945*	*2 894*	*3 637*	*3 147*
Chloride Cl	*mg/litre*	*19 000*	*20 900*	*20 267*	*19 000*	*21 200*	*20 367*
Alkalinity as $CaCO_3$	*mg/litre*	*115*	*118*	*117*	*112*	*117*	*115*
Nitrate plus Nitrite as N	*mg/litre*	*0.074*	*0.227*	*0.141*	*0.063*	*0.115*	*0.085*
Nitrate as NO_3	*mg/litre*	*0.071*	*0.224*	*0.137*	*0.060*	*0.107*	*0.080*
Nitrite as NO_2	*mg/litre*	*0.003*	*0.006*	*0.004*	*0.003*	*0.008*	*0.005*
Ortho phosphate as P	*mg/litre*	*0.009*	*0.036*	*0.023*	*0.004*	*0.029*	*0.018*
Fluoride as F	*mg/litre*	*0.9*	*1.2*	*1.0*	*0.8*	*1.4*	*1.0*
DOC	*mg/litre*	*NA*	*NA*	*< 1.0*	*NA*	*NA*	*< 1.0*
Conductivity (25°C)	*µS/cm*	*52 333*	*50 000*	*56 000*	*50 000*	*54 000*	*51 667*
pH (20°C)	*-*	*8.0*	*8.0*	*8.0*	*7.7*	*7.8*	*7.7*
pHs (20°C)	*-*	*7.1*	*7.0*	*7.2*	*7.1*	*7.1*	*7.1*
Total Dissolved Solids (TDS)	*mg/litre*	*33 493*	*32 000*	*35 840*	*32 000*	*34 560*	*33 067*
Hardness as $CaCO_3$	*mg/litre*	*6 349*	*6 297*	*6 436*	*6 041*	*8 584*	*6 978*
Sodium Adsorption Ratio	*-*	*60.1*	*59.0*	*61.2*	*60.7*	*65.0*	*62.2*
Ryznar Index	*-*	*6.2*	*6.0*	*6.3*	*6.0*	*6.5*	*6.2*
Kjeldahl Nitrogen as N	*mg/litre*	*NA*	*NA*	*< 1.00*	*NA*	*NA*	*< 1.0*
Boron as B	*mg/litre*	*-*	*-*	*4.3*	*-*	*-*	*4.3*
Silica as Si	*mg/litre*	*-*	*-*	*0.2*	*-*	*-*	*0.4*
Strontium as Sr	*mg/litre*	*-*	*-*	*7.5*	*-*	*-*	*7.4*
Bromide as Br	*mg/litre*	*-*	*-*	*0.041*	*-*	*-*	*0.042*
Iron as Fe	*mg/litre*	*-*	*-*	*<0.005*	*-*	*-*	*<0.005*
Manganese as Mn	*mg/litre*	*-*	*-*	*<0.001*	*-*	*-*	*<0.001*

Table 5.2.2 *– Water characterisation: combined streams statistics*

	MEAN	STD DEVIATION	MINIMUM	MAXIMUM
INFLUENT				
Conductivity (µS/cm)	*43 422*	*1 652*	*38 932*	*47 006*
Salinity (mg/litre)	*35 294*	*186*	*34 790*	*35 550*
Specific Conductivity (µS/cm)	*53 457*	*213*	*52 981*	*53 751*
TDS (mg/litre)	*37 420*	*149*	*37 086*	*37 625*
Temperature (°C)	*15.2*	*1.6*	*11.0*	*18.8*
Barometric Pressure (kPa)	*101.7*	*0.6*	*100.7*	*102.7*
Dissolved Oxygen (mg/litre)	*8.3*	*0.5*	*6.8*	*9.8*
pH (mg/litre)	*8.1*	*0.2*	*7.0*	*8.4*
EFFLUENT				
Conductivity (µS/cm)	*43 325*	*1 672*	*38 863*	*47 651*
Salinity (mg/litre)	*35 293*	*210*	*34 190*	*35 530*
Specific Conductivity (µS/cm)	*53 459*	*247*	*52 074*	*53 735*
TDS (mg/litre)	*37 421*	*173*	*36 449*	*37 611*
Temperature (°C)	*15.1*	*1.6*	*10.9*	*19.3*
Barometric Pressure (kPa)	*101.7*	*0.6*	*100.7*	*102.7*
Dissolved Oxygen (mg/litre)	*7.6*	*0.6*	*6.8*	*9.7*
pH (mg/litre)	*7.9*	*0.1*	*7.7*	*8.1*
EFFLUENT$_{200µm}$				
Conductivity (µS/cm)	*43 881*	*1 865*	*39 122*	*49 422*
Salinity (mg/litre)	*35 304*	*186*	*34 790*	*35 540*
Specific Conductivity (µS/cm)	*53 459*	*220*	*52 764*	*53 727*
TDS (mg/litre)	*37 421*	*154*	*36 932*	*37 611*
Temperature (°C)	*15.6*	*1.8*	*11.2*	*20.9*
Barometric Pressure (kPa)	*101.7*	*0.6*	*100.7*	*102.7*
Dissolved Oxygen (mg/litre)	*7.4*	*0.6*	*6.5*	*9.3*
pH (mg/litre)	*7.9*	*0.1*	*7.7*	*8.1*
UF FEED				
Conductivity (µS/cm)	*43 737*	*1 630*	*39 308*	*48 643*
Salinity (mg/litre)	*35 289*	*322*	*32 840*	*35 790*
Specific Conductivity (µS/cm)	*53 440*	*432*	*50 058*	*54 127*
TDS (mg/litre)	*37 408*	*303*	*35 042*	*37 891*
Temperature (°C)	*15.5*	*1.6*	*11.3*	*21.5*
Barometric Pressure (kPa)	*101.7*	*0.6*	*100.7*	*102.8*
Dissolved Oxygen (mg/litre)	*7.7*	*0.5*	*6.8*	*9.1*
pH (mg/litre)	*8.0*	*0.1*	*7.4*	*8.3*

Table 5.2.2 *– Water characterisation: combined streams statistic (continued)*

	MEAN	STD DEVIATION	MINIMUM	MAXIMUM
UF PERMEATE				
Conductivity (µS/cm)	*44 207*	*1 497*	*39 717*	*48 777*
Salinity (mg/litre)	*35 221*	*538*	*30 810*	*35 540*
Specific Conductivity (µS/cm)	*53 434*	*241*	*52 671*	*53 742*
TDS (mg/litre)	*37 331*	*512*	*33 096*	*37 618*
Temperature (°C)	*16.0*	*1.5*	*11.8*	*22.1*
Barometric Pressure (kPa)	*101.7*	*0.6*	*100.7*	*102.8*
Dissolved Oxygen (mg/litre)	*7.4*	*0.5*	*5.4*	*8.7*
pH (mg/litre)	*7.6*	*0.5*	*6.2*	*8.0*
RO FEED				
Conductivity (µS/cm)	*44 350*	*1 482*	*40 303*	*48 893*
Salinity (mg/litre)	*35 064*	*872*	*29 840*	*35 540*
Specific Conductivity (µS/cm)	*53 377*	*333*	*52 151*	*53 744*
TDS (mg/litre)	*37 176*	*836*	*32 151*	*37 618*
Temperature (°C)	*16.4*	*1.6*	*12.4*	*22.2*
Barometric Pressure (kPa)	*101.7*	*0.5*	*100.7*	*102.7*
Dissolved Oxygen (mg/litre)	*7.6*	*0.5*	*6.0*	*8.8*
pH (mg/litre)	*7.5*	*0.6*	*5.5*	*8.1*
RO PERMEATE				
Conductivity (µS/cm)	*1 600*	*206*	*1 297*	*2 174*
Salinity (mg/litre)	822	87	690	1 080
Specific Conductivity (µS/cm)	*1 629*	*167*	*1 383*	*2 122*
TDS (mg/litre)	897	92	759	1 166
Temperature (°C)	*23.9*	*1.7*	*19.1*	*29.1*
Barometric Pressure (kPa)	*101.7*	*0.5*	*100.7*	*102.8*
Dissolved Oxygen (mg/litre)	*8.1*	*0.6*	*5.8*	*9.7*
pH (mg/litre)	*6.8*	*0.7*	*5.4*	*7.9*
RO CONCENTRATE				
Conductivity (µS/cm)	*86 850*	*3 539*	*78 824*	*98 067*
Salinity (mg/litre)	*61 079*	*1 412*	*55 960*	*69 030*
Specific Conductivity (µS/cm)	*86 337*	*1 701*	*80 158*	*95 819*
TDS (mg/litre)	*64 755*	*1 271*	*60 150*	*71 850*
Temperature (°C)	*25.3*	*1.7*	*20.3*	*29.8*
Barometric Pressure (kPa)	*101.7*	*0.5*	*100.7*	*102.7*
Dissolved Oxygen (mg/litre)	*5.5*	*0.3*	*5.1*	*6.4*
pH (mg/litre)	*7.5*	*0.4*	*6.1*	*7.9*

5.2.1 Water Temperature

The trends for water temperature are presented in Figures 5.2.1a and 5.2.1b with moving averages (period of 2). Figure 5.2.1a presents the temperatures for the streams leading up to the pilot plant (influent, effluent and effluent$_{200\mu m}$) whilst Figure 5.2.1b presents the temperatures for the streams concerning the pilot plant (UF feed, UF permeate, RO feed, RO permeate and RO concentrate).

An increase in water temperature increases both permeate water flow rate and salt flow rate through the membrane (therefore not affecting permeate salinity), it decreases the viscosity of the water, requiring lower feed pressures to maintain the same flux which results in an increase in permeate salinity (at constant flux). SWRO pilot plant performance data are normalised for temperature (typically to 25°) when comparisons are to be made between performances observed at different temperatures.

The seasonal change in temperature is very clear on this plot. In the Western Cape, South Africa, summer is typically from December to March, autumn is from April to June and winter from June to August.

For the streams leading up to the SWRO desalination pilot plant the highest water temperatures were observed during the summer month of March (~ 20°C); the lowest water temperatures were observed during the autumn month of April (~ 10°C) and it then stabilised at about 15°C during the winter months of June and July. One would expect a gradual decrease in water temperature from summer to winter. The sudden temperature drop during April was most probably due to oceanic currents changing with the change in seasons from summer to autumn and autumn to winter – since the winter water temperatures (June/July) were higher than the lowest temperatures observed during autumn.

When designing a commercial scale SWRO desalination plant it is recommended that the design should accommodate feed water temperatures ranging from 10 – 20°C with possible sudden temperature drops of as much as 10°C within a week.

The temperature of the SWRO pilot plant RO permeate and RO concentrate was on average, depending on ambient conditions, 6 – 8°C higher than the RO feed temperatures, due to the high amounts of kinetic energy that was added to the water by recycling in the ‘feed-and-bleed’ RO operation.

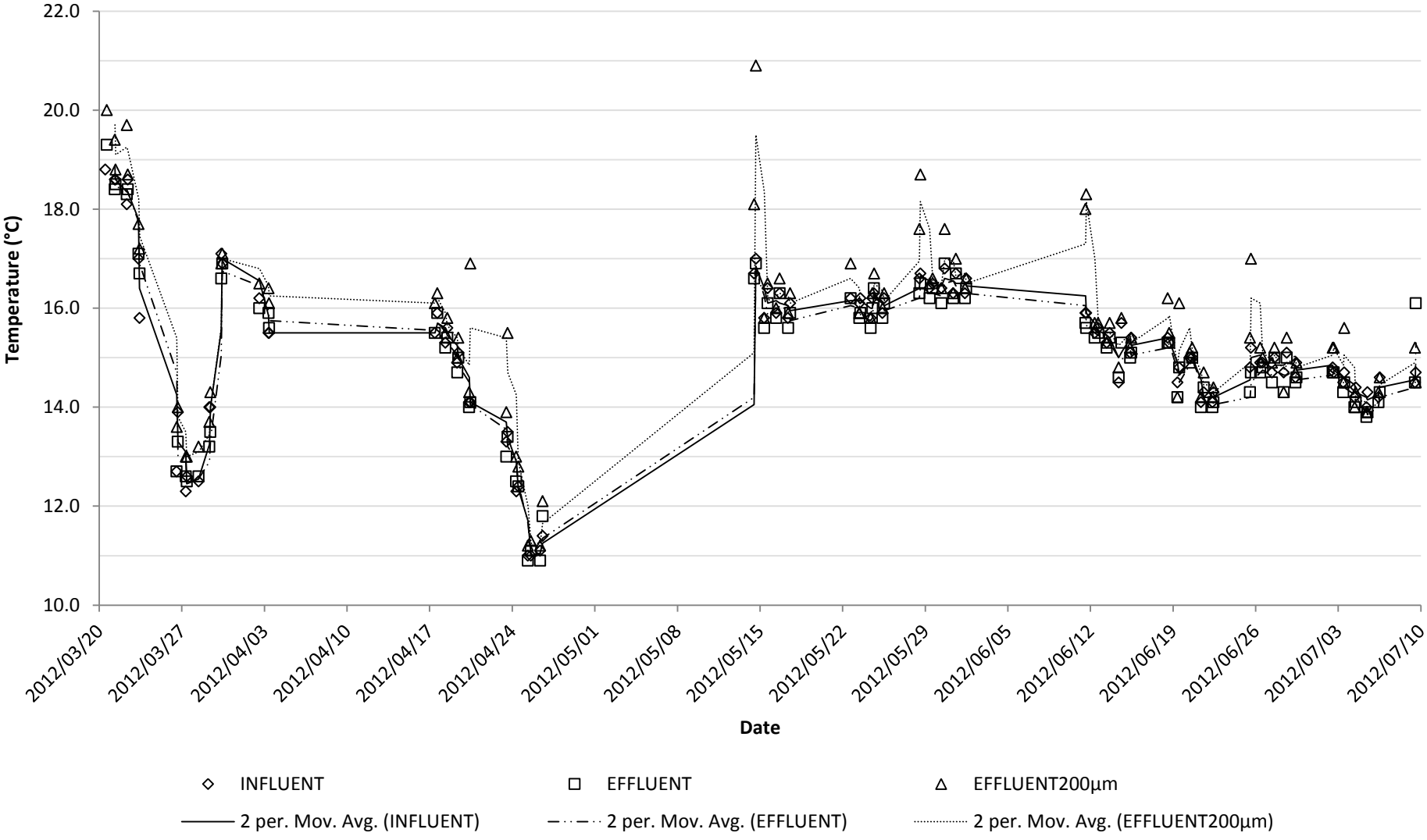

Figure 5.2.1a *– Influent, effluent and effluent$_{200\mu m,}$ stream temperature*

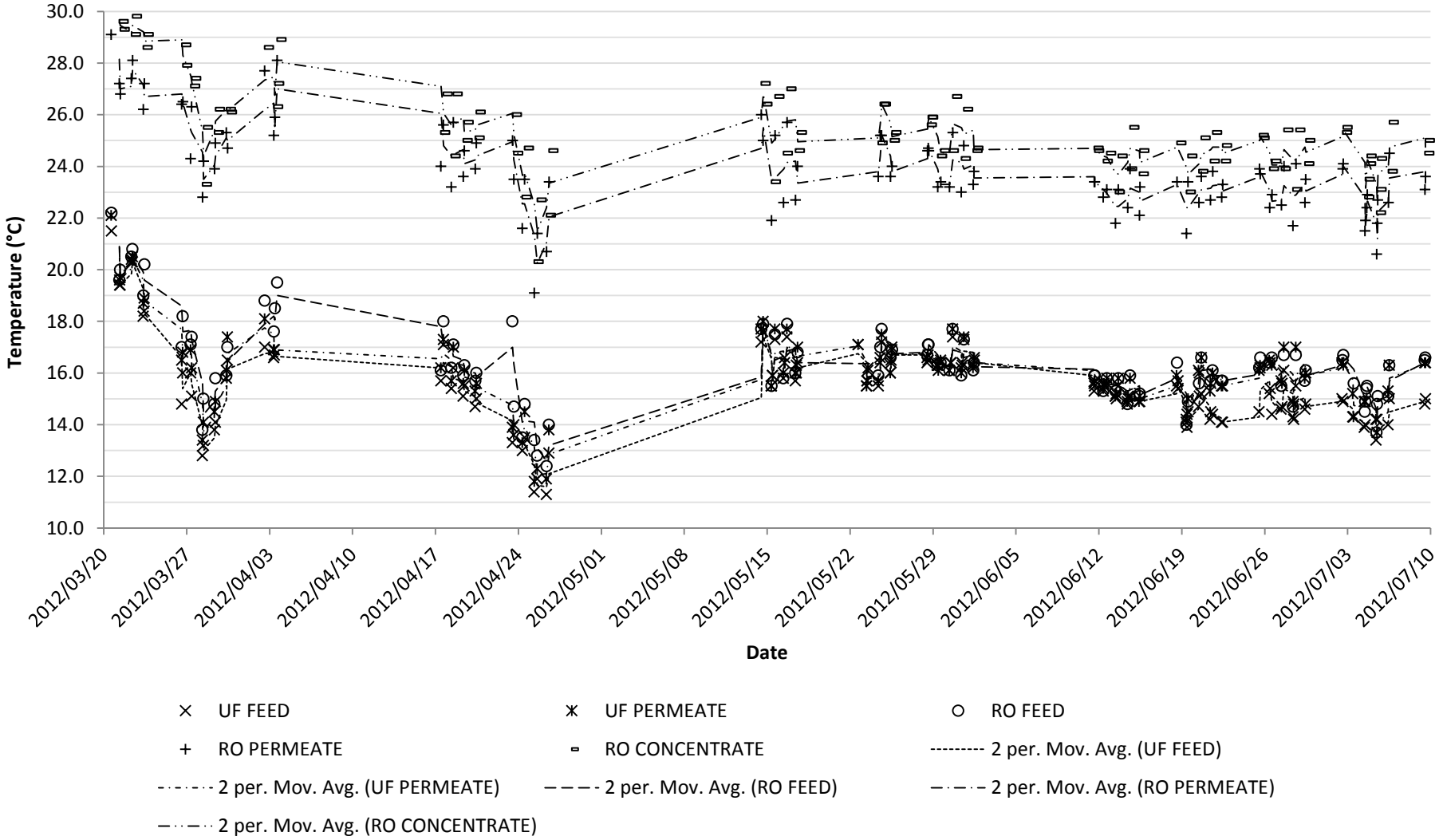

Figure 5.2.1b *– UF feed/permeate and RO feed/permeate/concentrate stream temperature*

5.2.2 Specific Conductivity

The trends for specific conductivity are presented in Figures 5.2.2a, 5.2.2b and 5.2.2c with moving averages (period of 2). Figure 5.2.2a presents the specific conductivity for the influent, effluent, effluent$_{200\mu m}$, UF feed, UF permeate and RO feed streams since they all have similar specific conductivities. In addition, the specific conductivity of the RO permeate is shown in Figure 5.2.2b and that of the RO concentrate is presented in Figure 5.2.2c.

From figure 5.2.2a the specific conductance remained relatively unchanged between the influent, effluent, effluent$_{200\mu m}$, UF feed, UF permeate and RO feed streams, with specific conductivities ranging between 52 000 and 54 000 µS/cm. These values are typical of Atlantic sea water (El-Dessouky & Ettouney 2002).

From Figure 5.2.2b the RO produced good quality permeate, for the last membrane in a membrane bank, with specific conductance ranging between 1 380 and 2 130 µS/cm and a mean value of 1 630 µS/cm over the four months it was measured. It should be kept in mind that the feed stream was concentrated by the 'feed-and-bleed' system simulating the last membrane in a full-scale RO membrane bank or train. The specific conductivity of the concentrated membrane feed stream is discussed with the performance data for the pilot plant. Furthermore Figure 5.2.3c shows that the RO concentrate specific conductance ranged between 80 000 – 96 000 µS/cm with a mean value of 86 300 µS/cm.

A commercial scale SWRO desalination plant in this area should be designed to operate with feed water specific conductance ranging between 50 000 – 55 000 µS/cm. The changes in specific conductivity are more subtle than the changes observed for water temperature.

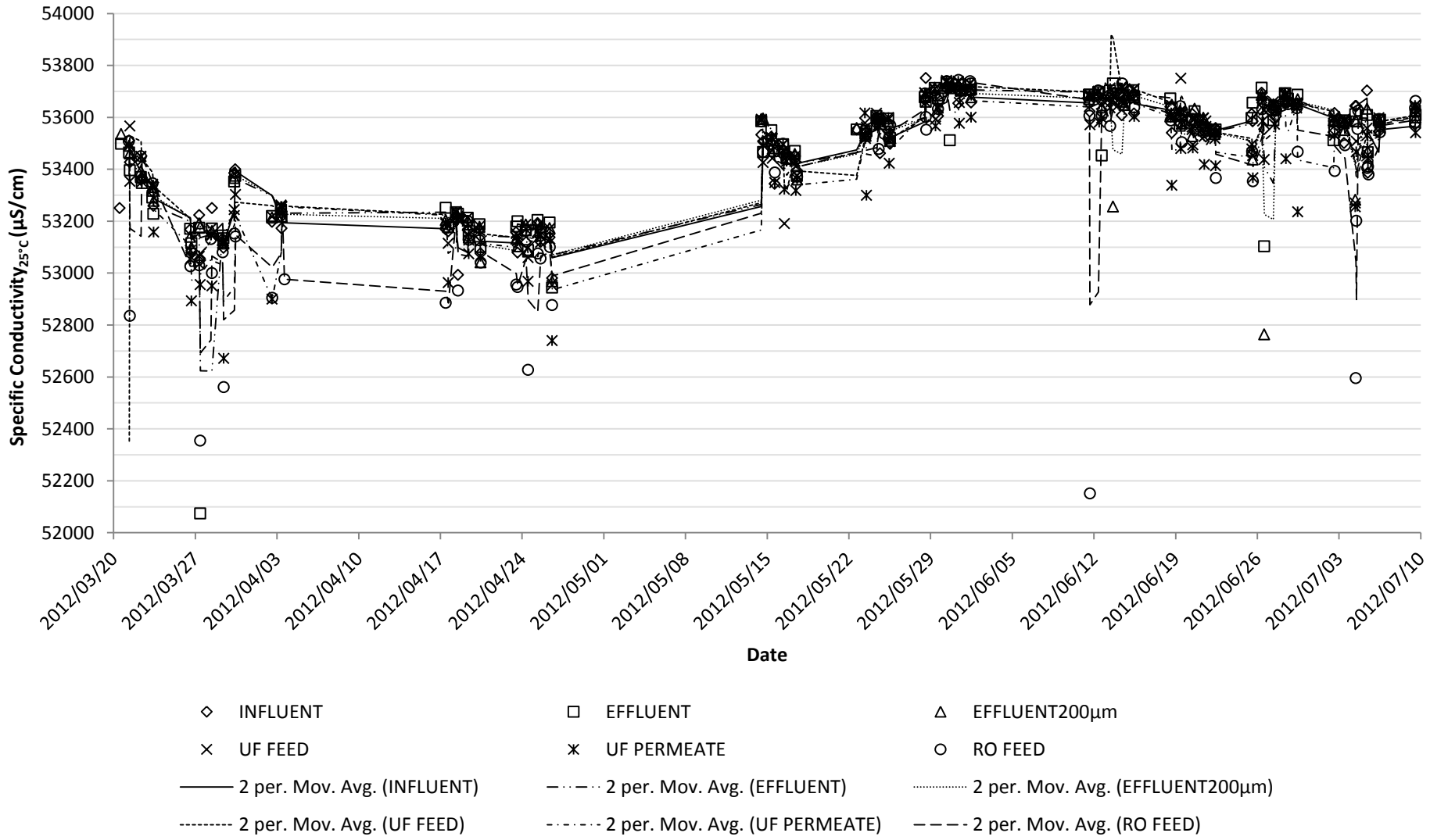

Figure 5.2.2a *– Influent, effluent, effluent$_{200\mu m}$, UF feed, UF permeate and RO feed stream specific conductivity*

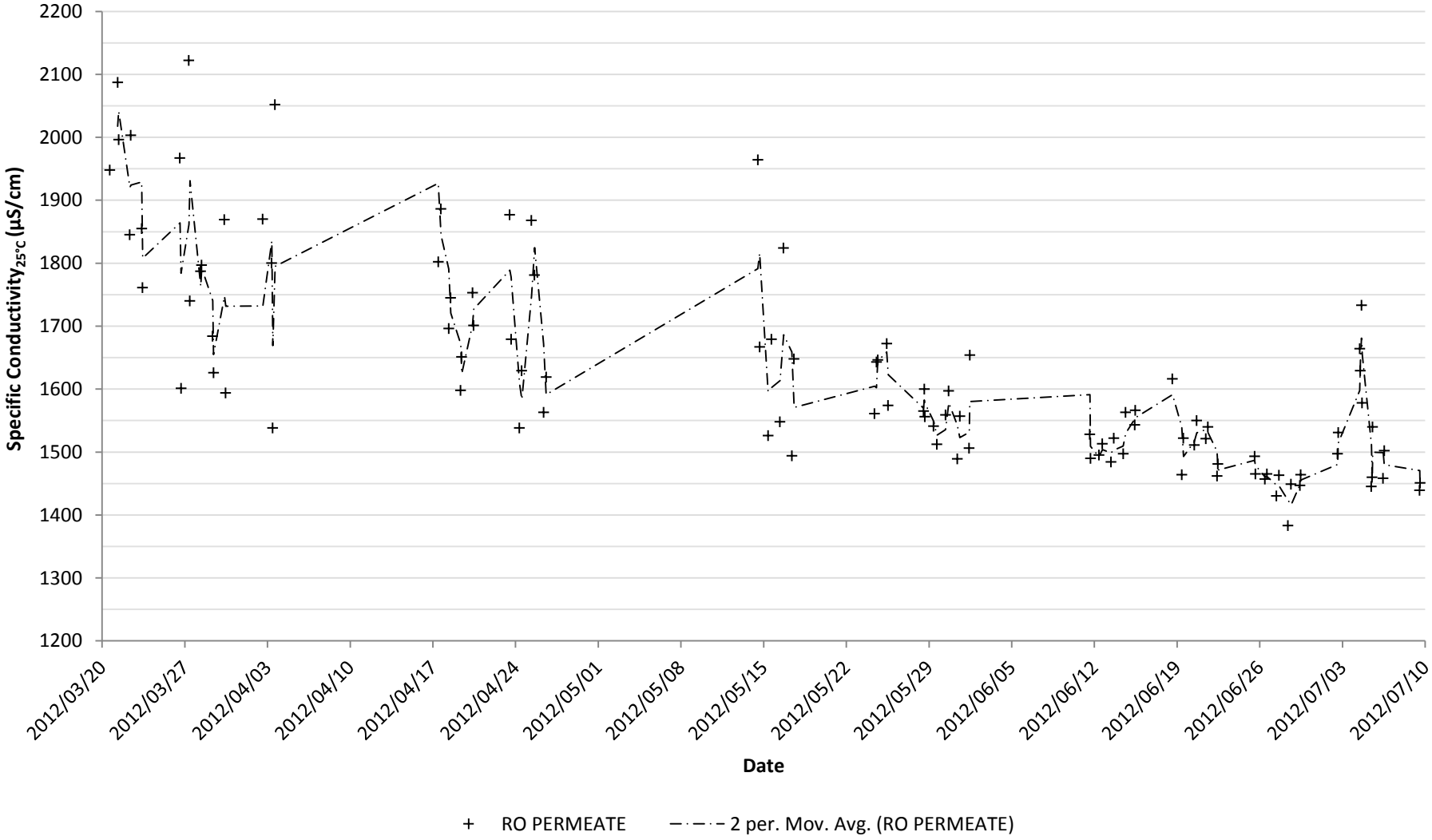

Figure 5.2.2b *– RO permeate stream specific conductivity*

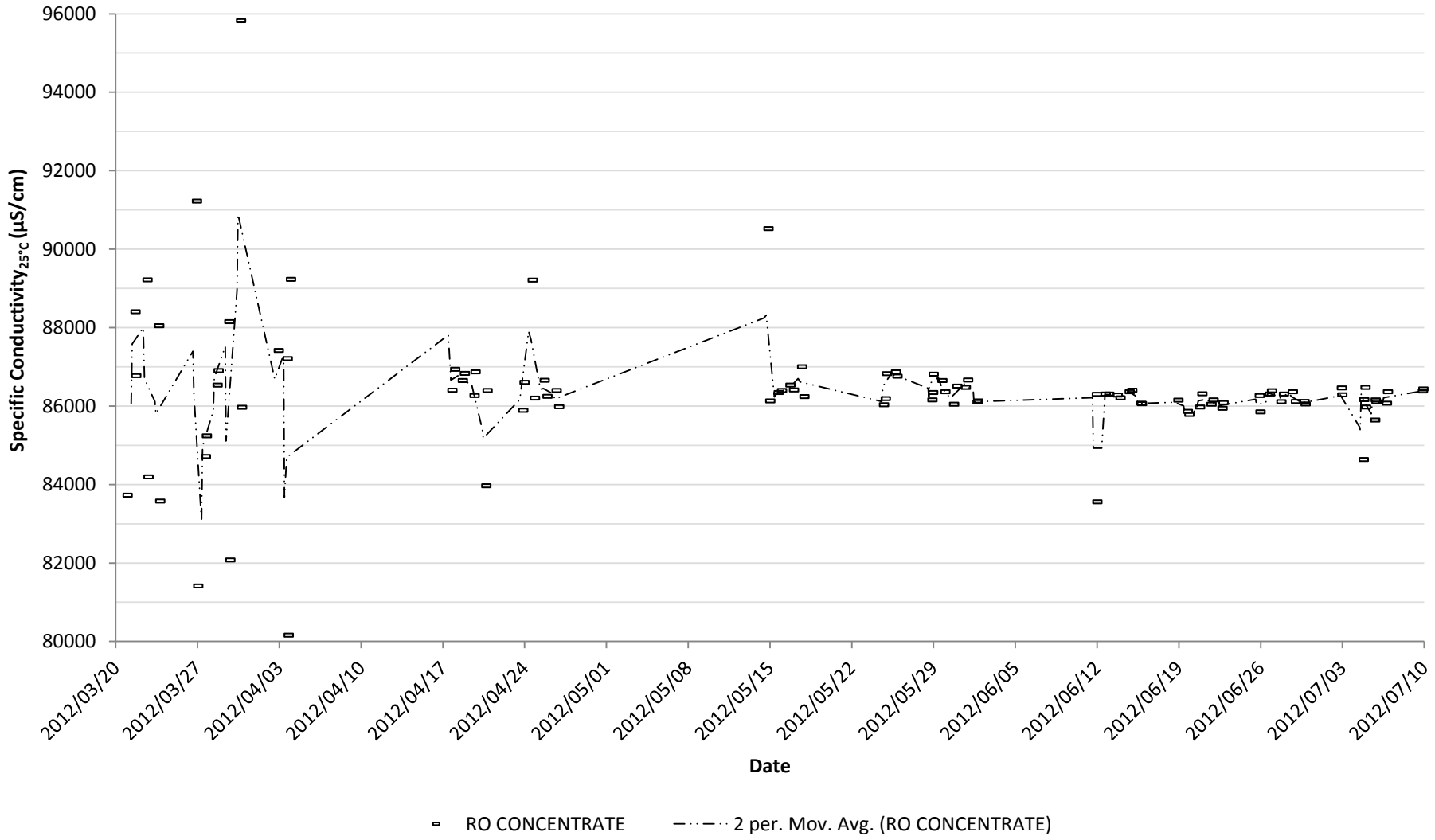

Figure 5.2.2c *– RO concentrate stream specific conductivity*

5.2.3 Total Dissolved Solids

The relationship between specific conductivity and TDS has been discussed in section 4.3.4. Based on that discussion the trends of TDS will be similar to that of specific conductivity. The trends for TDS are presented in Figures 5.2.3a, 5.2.3b and 5.2.3c with moving averages (period of 2).

TDS trends for the influent, effluent, effluent$_{200\mu m}$, UF feed, UF permeate and RO feed streams are presented in Figure 5.2.3a. From here it can be seen that the TDS concentrations for the influent, effluent, effluent$_{200\mu m}$, UF feed, UF permeate and RO feed streams varied largely between 36 400 – 38 000 mg/litre.

From Figure 5.2.3b the RO permeate TDS ranged between 700 and 1200 mg/L TDS. In addition Figure 5.2.3c shows that the RO concentrate TDS ranged largely between 60 000 and 70 000 mg/litre.

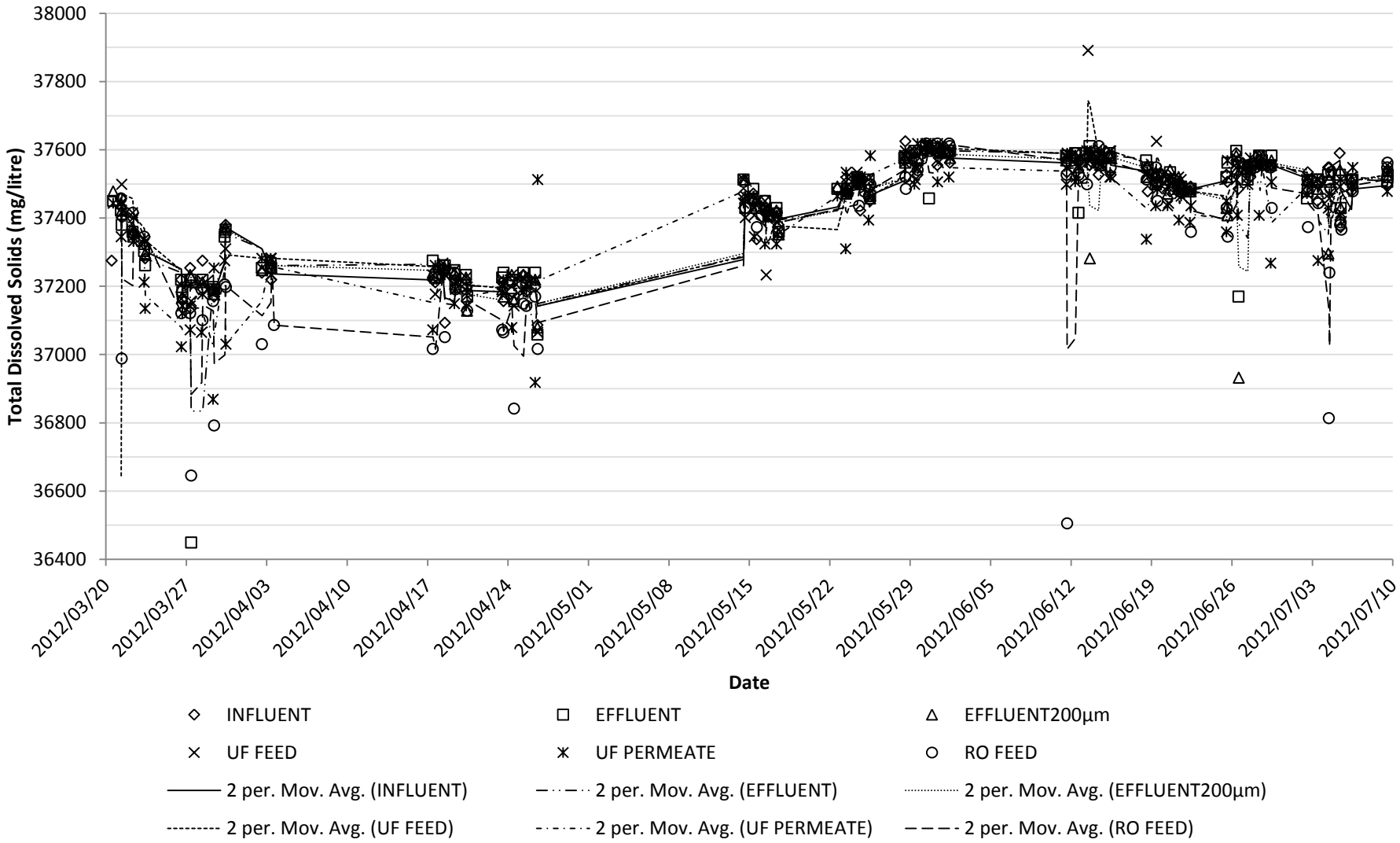

Figure 5.2.3a *– Influent, effluent, effluent$_{200\mu m}$, UF feed, UF permeate and RO feed stream TDS*

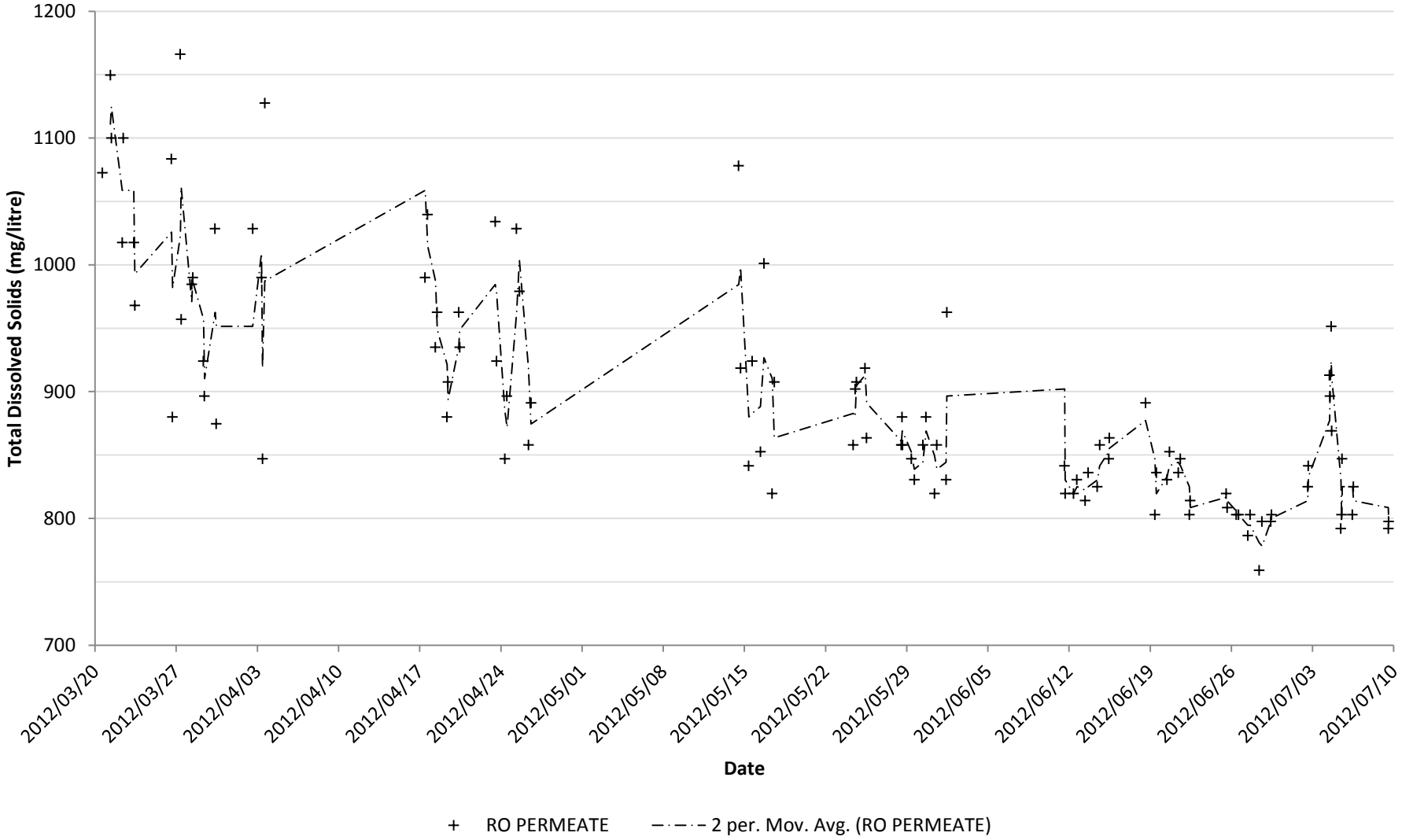

Figure 5.2.3b *– RO permeate stream TDS*

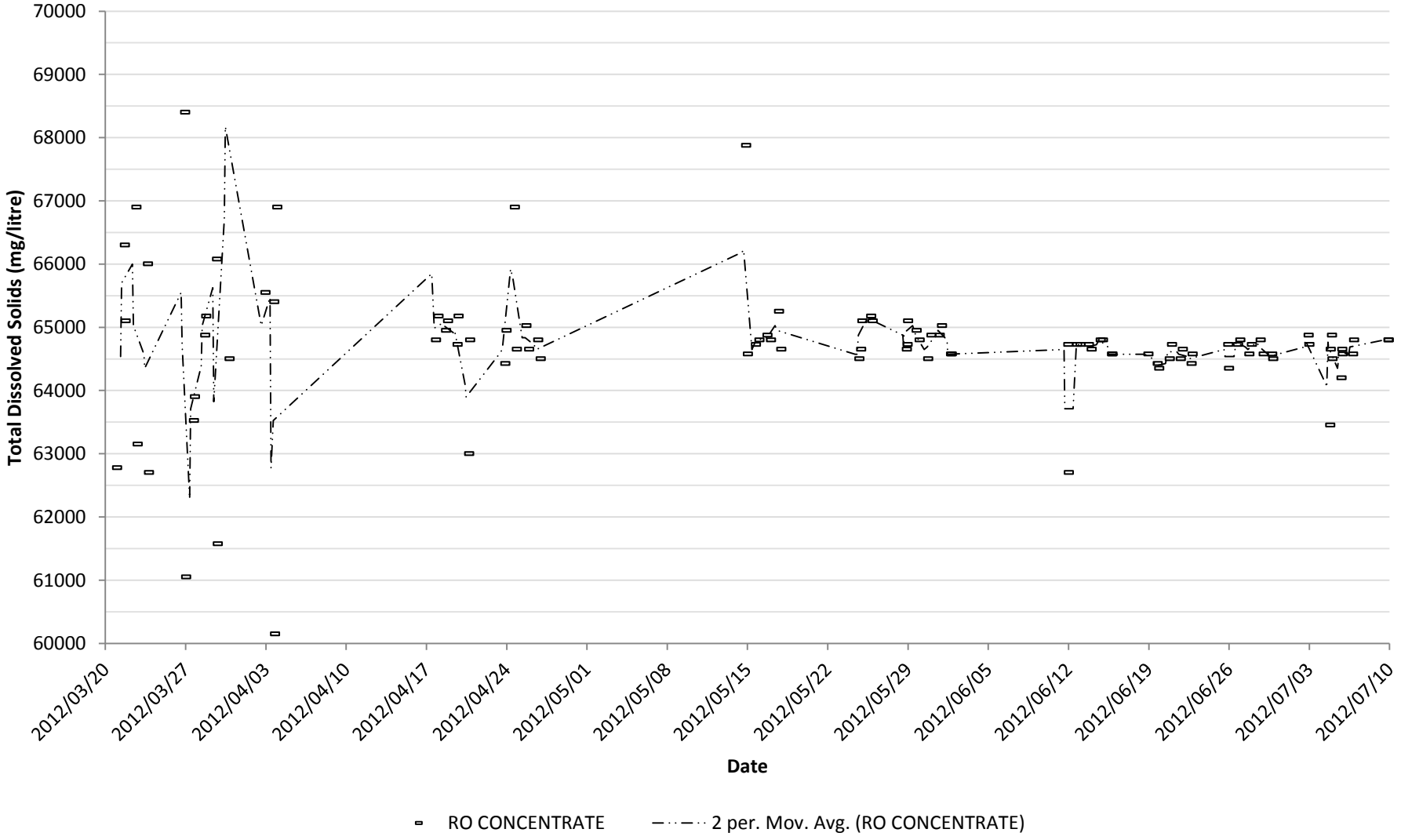

Figure 5.2.3c *– RO concentrate stream TDS*

5.2.4 Salinity

Similarly to TDS, the salinity is derived from conductivity and temperature readings by the YSI Pro Plus using built in algorithms based on research done on this relationship algorithms by Bennett (Bennett 1976) and Lewis (Lewis 1980). The trends for salinity for the different streams are presented in 5.2.4a, 5.2.4b and 5.2.4c with the lines representing the moving averages (period of 2).

Salinity for the influent, effluent, effluent$_{200\mu m}$, UF permeate and RO feed streams are presented in Figure 5.2.4a and varied mostly from 34 000 – 36 000 mg/litre. Figure 5.2.4b presents the RO permeate salinity that ranged between 600 and 1200 mg/litre whereas the RO concentrate salinity ranged largely between 56 000 – 70 000 mg/litre and is presented in Figure 5.2.3c.

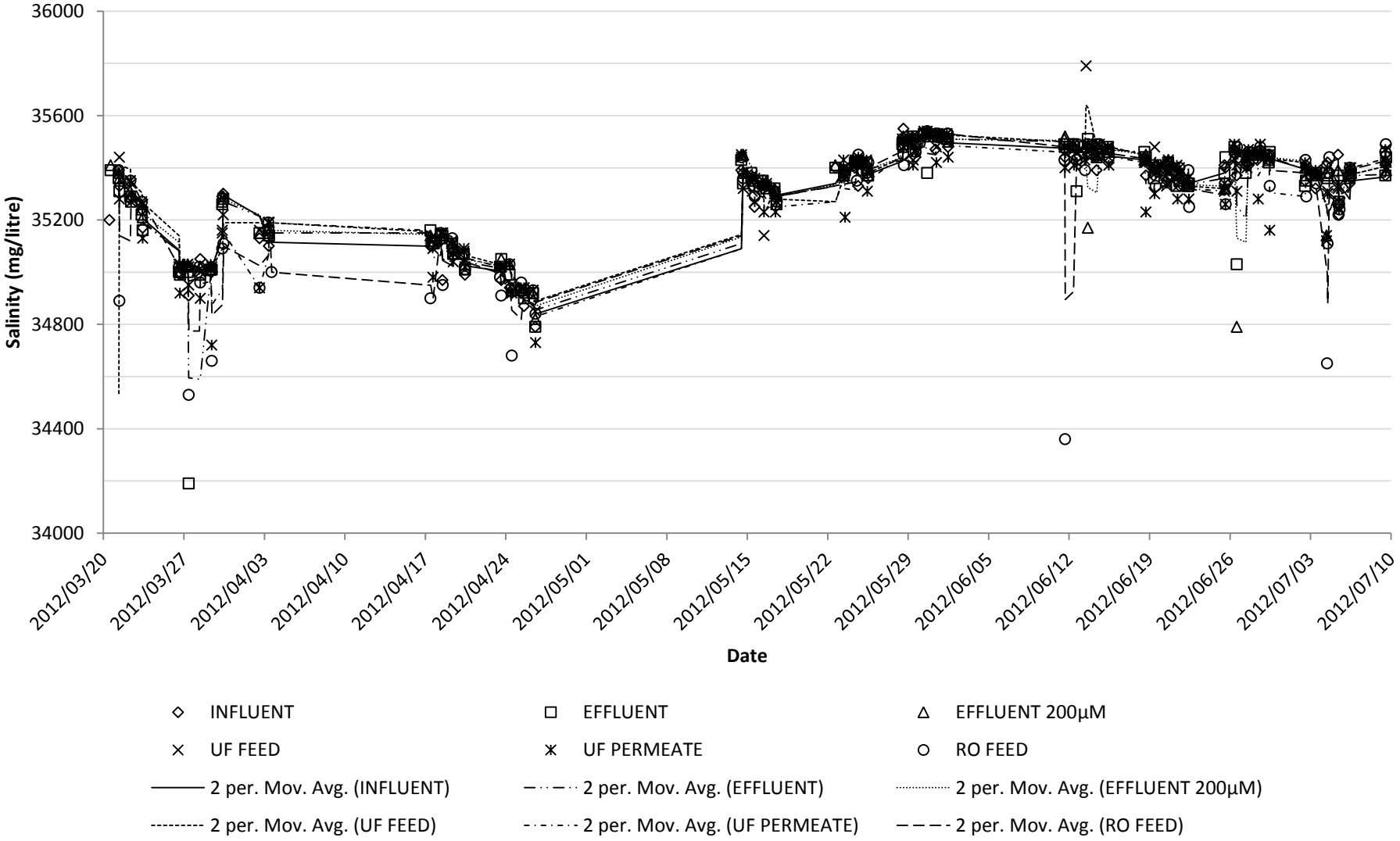

Figure 5.2.4a *– Influent, effluent, effluent 200µm, UF feed, UF permeate and RO feed stream salinity*

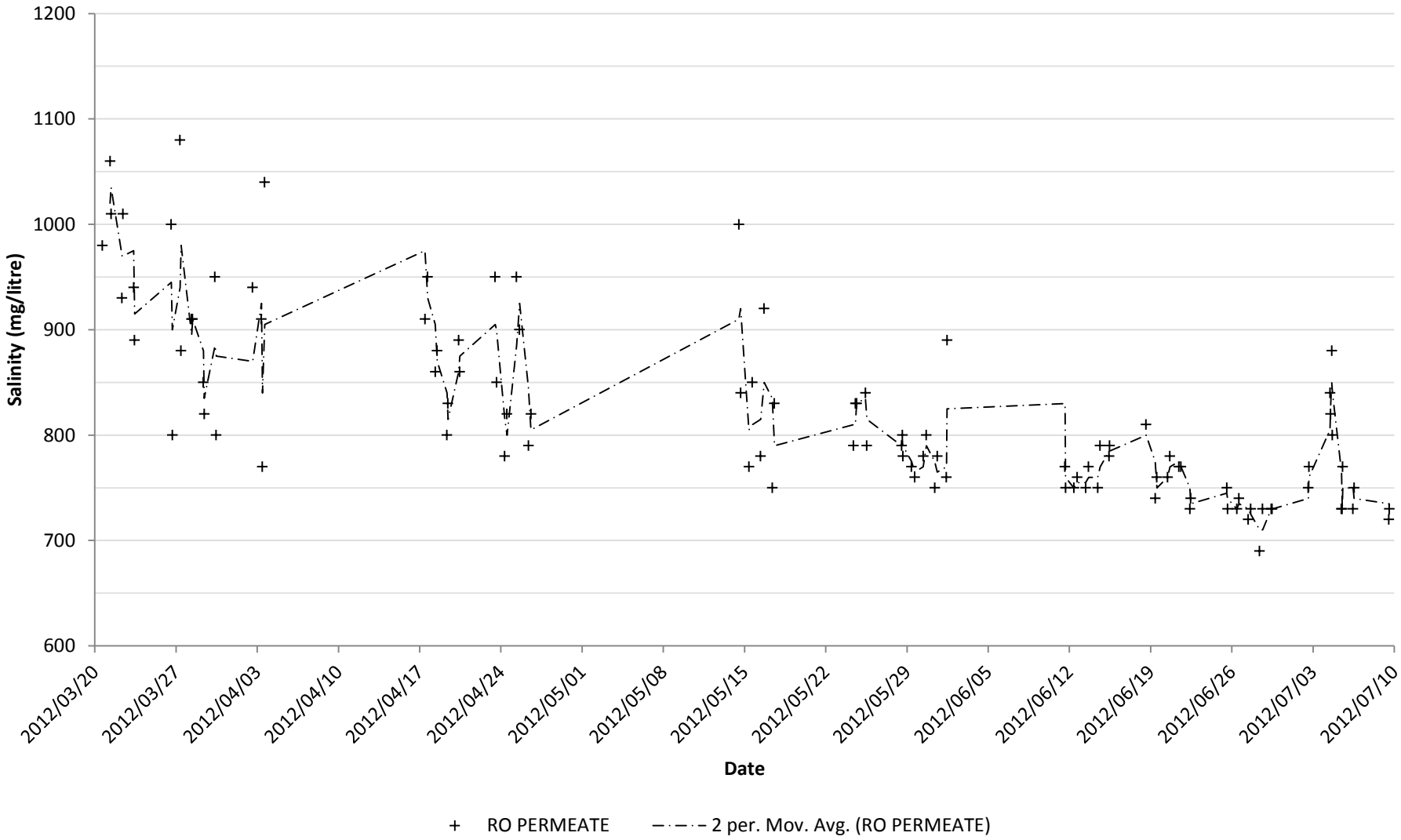

Figure 5.2.4b *– RO permeate stream salinity*

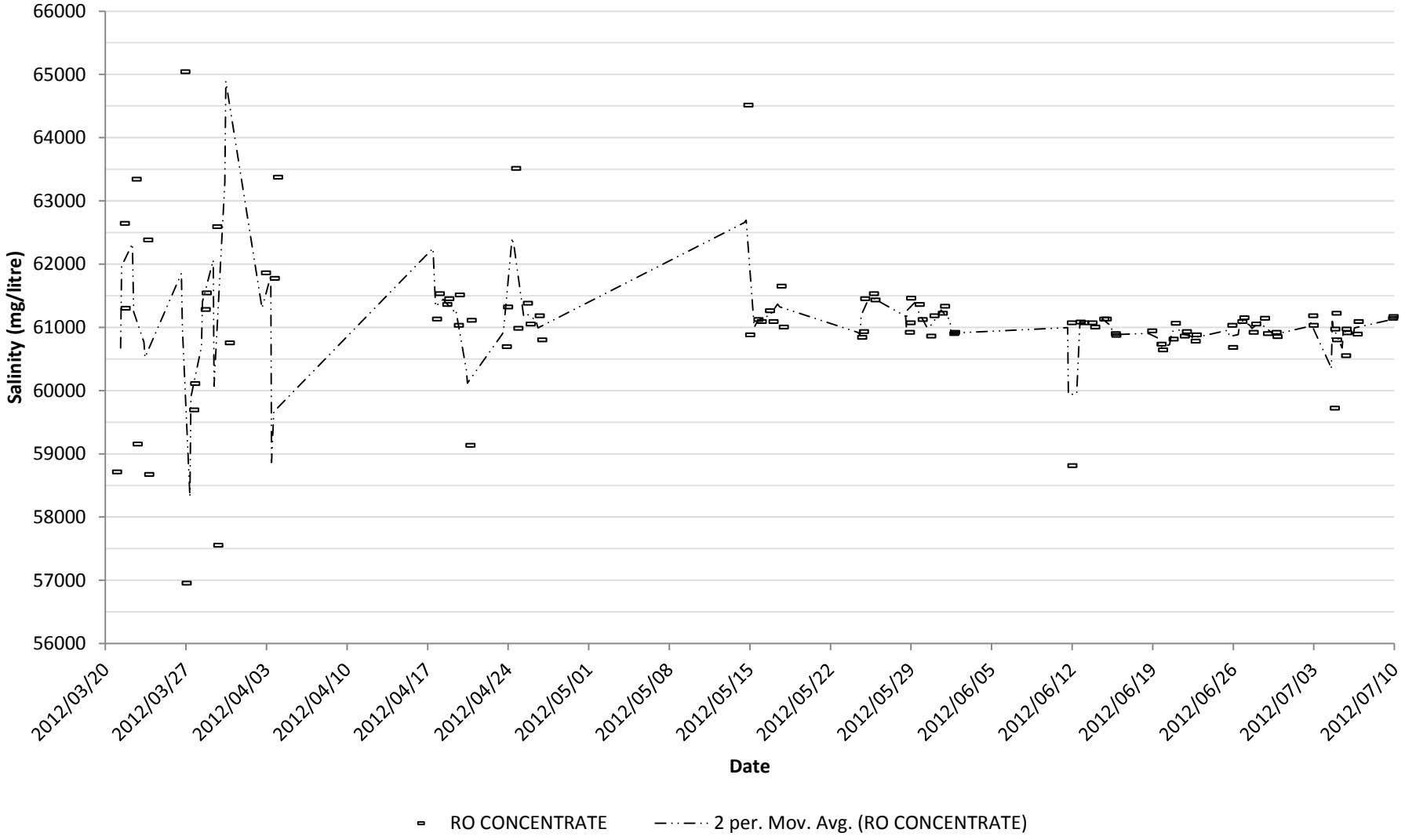

Figure 5.2.4c *– RO concentrate stream salinity*

5.2.5 Dissolved Oxygen

The moving average trends (period of 2) of DO in the sea water streams are presented in Figures 5.2.5a and 5.2.5b. Figure 5.2.5a presents the DO for the streams leading up to the pilot plant whilst Figure 5.2.5b presents the DO for the streams concerning the pilot plant.

The highest levels of DO are found in the influent and RO permeate streams with mean DO concentrations of 8.3 mg/litre, and 8.1 mg/litre respectively. The RO concentrate has the lowest DO concentration, with a mean value of 5.5 mg/L. The oxygen levels for the other streams all have mean values of approximately 7.5 mg/L.

Dissolved oxygen is dependent on the temperature and salinity of the water – the colder and less saline in the water the higher the solubility of oxygen. The effect of temperature on DO was evident from the subsequent rise in dissolved oxygen levels when the water temperature dropped in late March and April whilst the salinity for the streams remained relatively constant during this time. Although the RO permeate should have the highest levels of oxygen due to its low salinity, it was not due to its temperature being much higher than that of the influent. A factor that contributed to the scattering of data was change in the feeding behaviour (and therefore metabolic rate) of the molluscs.

Eriksson (1991) revealed that dissolved oxygen levels itself do not affect membrane performance. However, DO in the RO feed stream can influence the growth of aerobic bacteria. Lower levels of DO could hinder the growth of aerobic bacteria and consequently biofouling of the RO membrane.

Some water characterisation tests such as MFI and SDI can be affected by bubbles formed by DO in the water (Alhadidi *et al.* 2011). Therefore these effects had to be taken into account when these tests were performed.

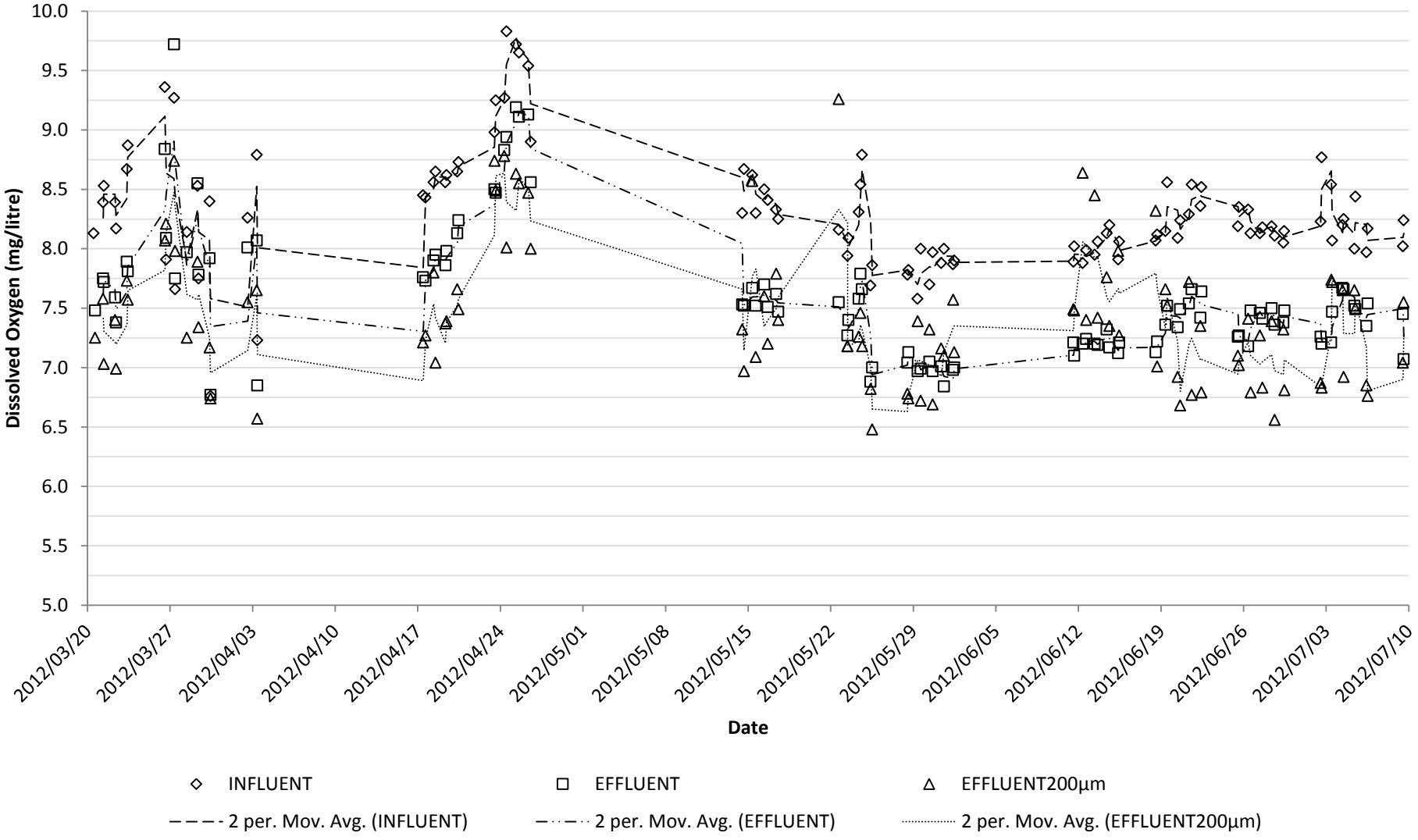

Figure 5.2.5a *– Influent, effluent and effluent$_{200\mu m}$ stream DO*

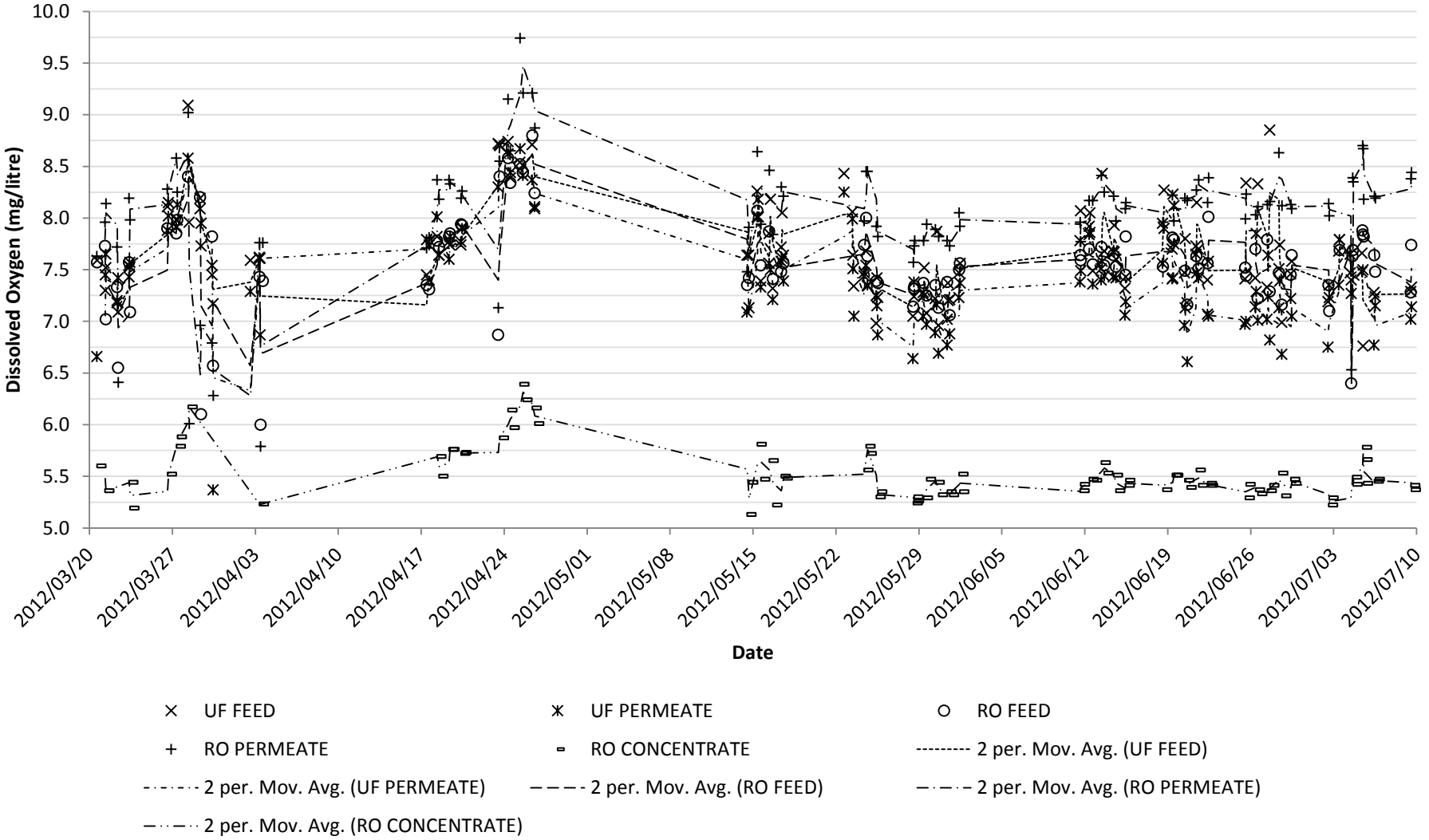

Figure 5.2.5b *– UF feed/permeate and RO feed/permeate/concentrate stream DO*

5.2.6 pH

The moving average trends (period of 2) of pH in the sea water streams are presented in Figures 5.2.6a and 5.2.6b. Figure 5.2.6a presents the pH for the streams leading up to the pilot plant whilst Figure 5.2.6b presents the pH for the streams concerning the pilot plant.

It has been mentioned that the respiration of the molluscs as well as the nitrification of ammonia in the tanks reduce the pH of the water as it flows through the tanks (Sanni & Forsberg 1996). Therefore the pH of the effluent stream is lower than that of the influent stream.

The dosing, dissociation and hydrolysation of ferric chloride in water release a H^+-ions, reducing the pH of the water, consequently the UF permeate stream had a lower pH than that of the UF feed stream during flocculation (see Appendix A for the coagulation reactions). In addition, variations in the pH of all the streams downstream of the ultra-filtration unit can be explained by the SMBS based de-chlorination after the CEB of the ultrafiltration membranes. One sample is taken before the CEB and one after the CEB every morning. De-chlorination with SMBS produces HCl and H_2SO_4, both strong acids. Furthermore, in practice, 3 mg/litre of SMBS was used per 1 mg/litre of free chlorine for de-chlorination instead of the stoichiometric required 1.34 SMBS per 1mg/litre chlorine (Fritzmann *et al.* 2007) to ensure no chlorine comes in contact with the RO membrane. One therefore sees low pH values in these streams in the post-CEB readings.

The changes in feed pH may alter the surface charge on membranes, which in turn can affect membrane performance (Childress & Elimelech 2000; Hagmeyer & Gimbel 1998; Tanninen & Nyström 2002; Peeters *et al.* 1998). A recent study by Hoang *et al.* (Hoang et al. 2010) showed that pH can have an effect on ion rejection and flux. The rejection of ions in a NaCl solution was investigated. At a pH 8 – 10 rejection was stable and comparable at 95%, rejection then fell steadily to approximately 90% at pH 5 where the isoelectric point (IEP) of the membrane was reached. The cation rejection reached a minimum value at this point and rose again to 95% whilst the anion rejection continued to fall to about 88% at pH 3 (Hoang *et al.* 2010). Membrane flux seemed to be unaffected across the entire pH range investigated (pH 3 – 10) (Childress & Elimelech 2000; Hoang *et al.* 2010). Therefore it could safely be assumed that the membrane performance in this study would be unaffected by the pH range observed for the RO feed stream (mean value of pH 7.5).

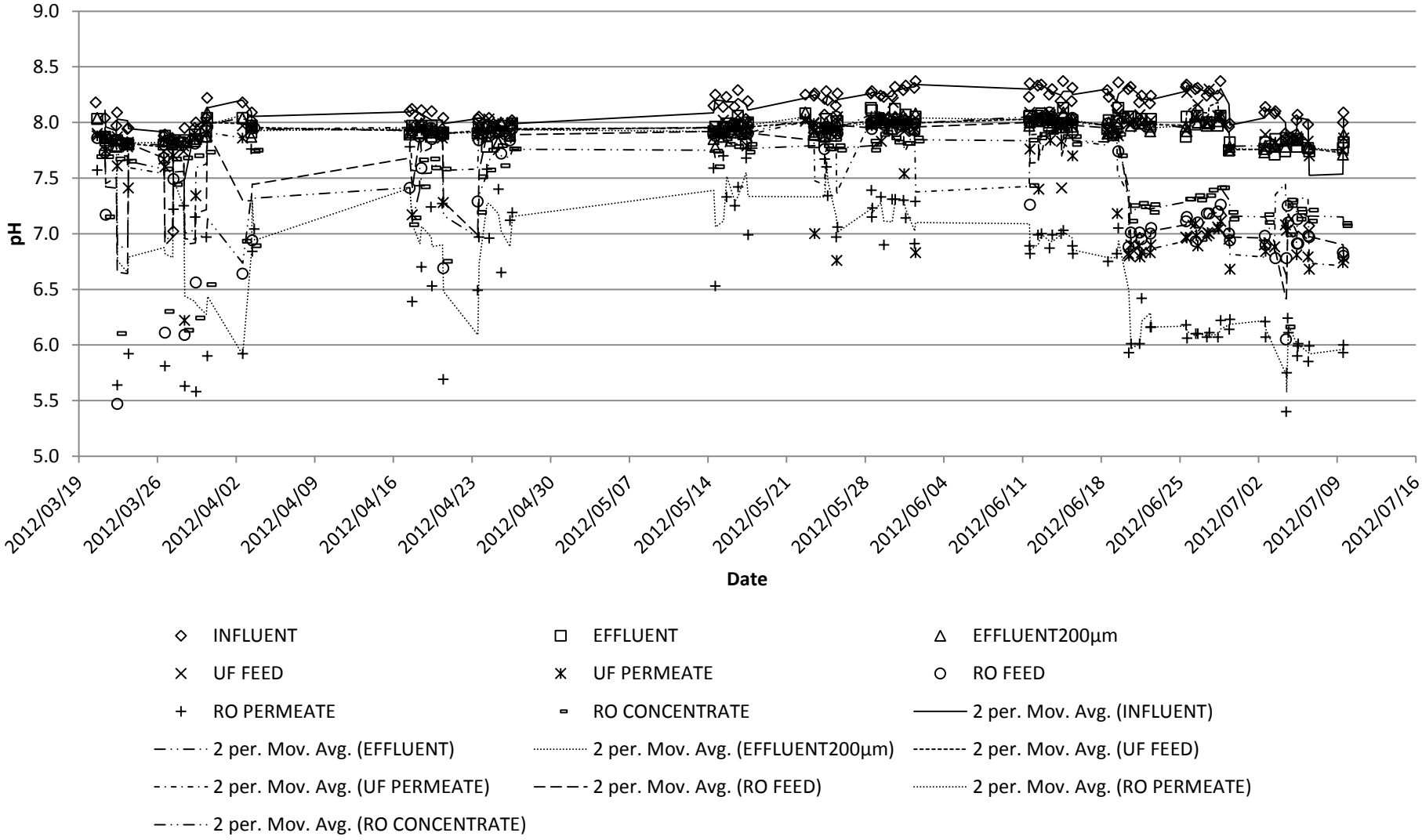

Figure 5.2.6a *– Influent, effluent and effluent$_{200\mu m}$ stream pH*

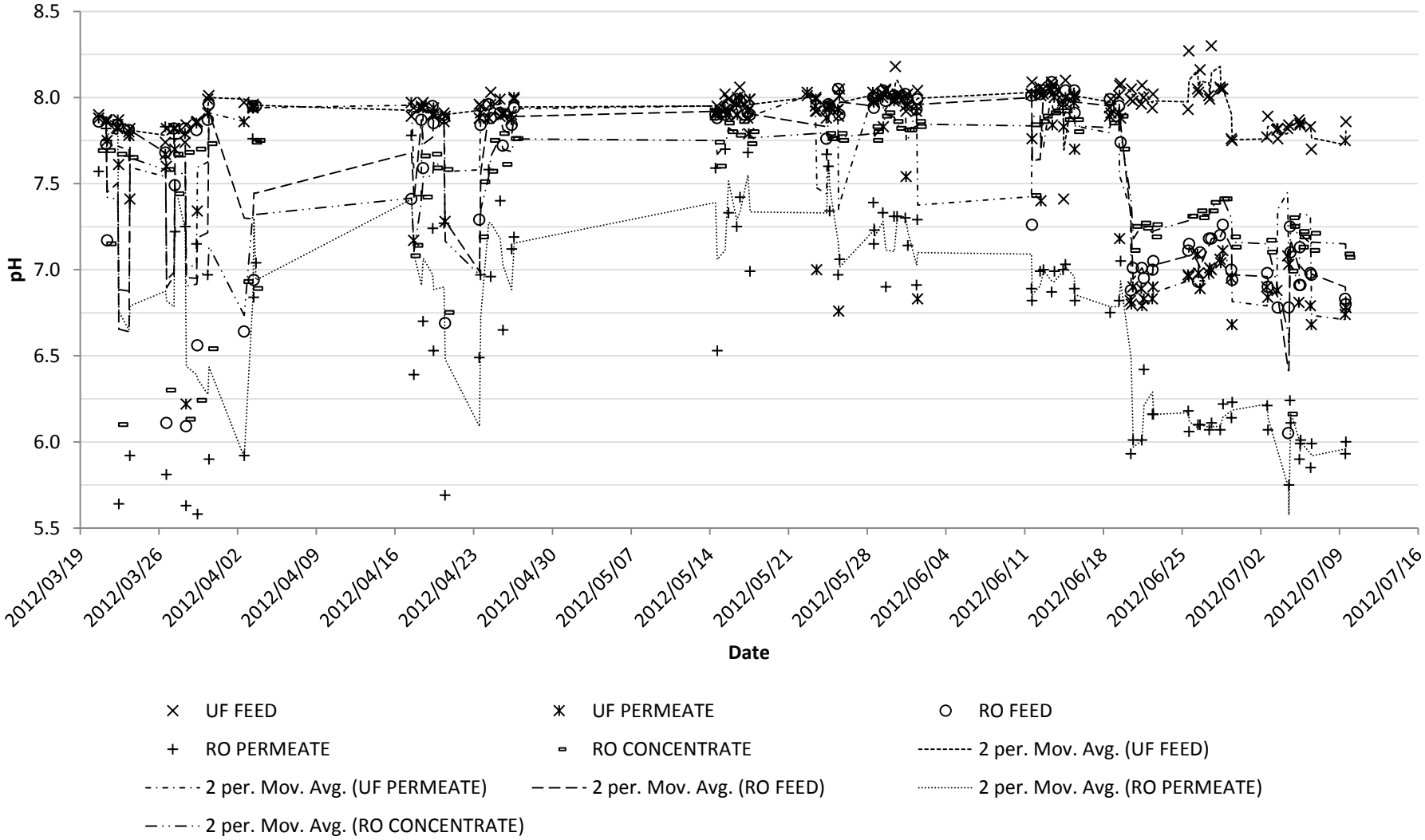

Figure 5.2.6b *– UF feed/ permeate and RO feed/permeate/concentrate stream pH*

5.2.7 Turbidity

The trends of turbidity are presented in Table 5.2.7 and Figure 5.2.7 respectively. From the data in Table 5.2.7, turbidity of the influent, effluent, effluent$_{200\mu m}$, UF permeate and RO permeate streams varied in the ranges of 0.22 – 2.17, 0.28 – 0.82, 0.33 – 0.97, 0.05 – 0.17 and 0.04 – 0.09 NTU respectively.

Table 5.2.7 *– Water characterisation: combined stream turbidity statistics*

STREAM	MEAN	STANDARD DEVIATION	MIN	MAX
Influent	*0.82*	*0.44*	*0.22*	*2.17*
Effluent	*0.47*	*0.12*	*0.28*	*0.82*
Effluent$_{200\mu m}$	*0.55*	*0.12*	*0.33*	*0.97*
UF permeate	*0.08*	*0.03*	*0.05*	*0.17*
RO permeate	*0.06*	*0.01*	*0.04*	*0.09*

Very high turbidity peaks of influent, effluent and effluent$_{200\mu m}$ appeared during unforeseen events, as labelled in Figure 5.2.7, which caused the sea water quality to degrade. A more detailed discussion of the specific events follows in Chapter 6 elaborating on the integration of a typical South African abalone farm with a commercial scale SWRO desalination plant. The overall descriptive statistics shows that the mean turbidity of the combined influent was decreased by almost 43% (from 0.82 to 0.47 NTU) as it flowed through the abalone tanks to become the combined effluent stream. It was interesting to note that even with high peaks in influent turbidity the effluent turbidity from the tanks were always <1.0 NTU which was a good indication for SWRO desalination pre-treatment. Furthermore a gradual increase in turbidity was observed as the influent water quality decreased with the seasonal change from summer to winter. The pre-treatment systems for an SWRO desalination plant integrated with an abalone farm should therefore make provision for possible water turbidity in the order of 1 NTU.

The UF permeate quality was excellent, regardless of the incoming turbidity, reinforcing the motivation for the use of UF instead of conventional pre-treatment as the UF membranes act as a physical barrier protecting the RO membranes. The possible damage to UF membranes by sudden deterioration in water quality should however not be overlooked – conventional media filtration with flocculation is more robust in this instance but may also not provide the required quality filtrate for good RO performance during these periods.

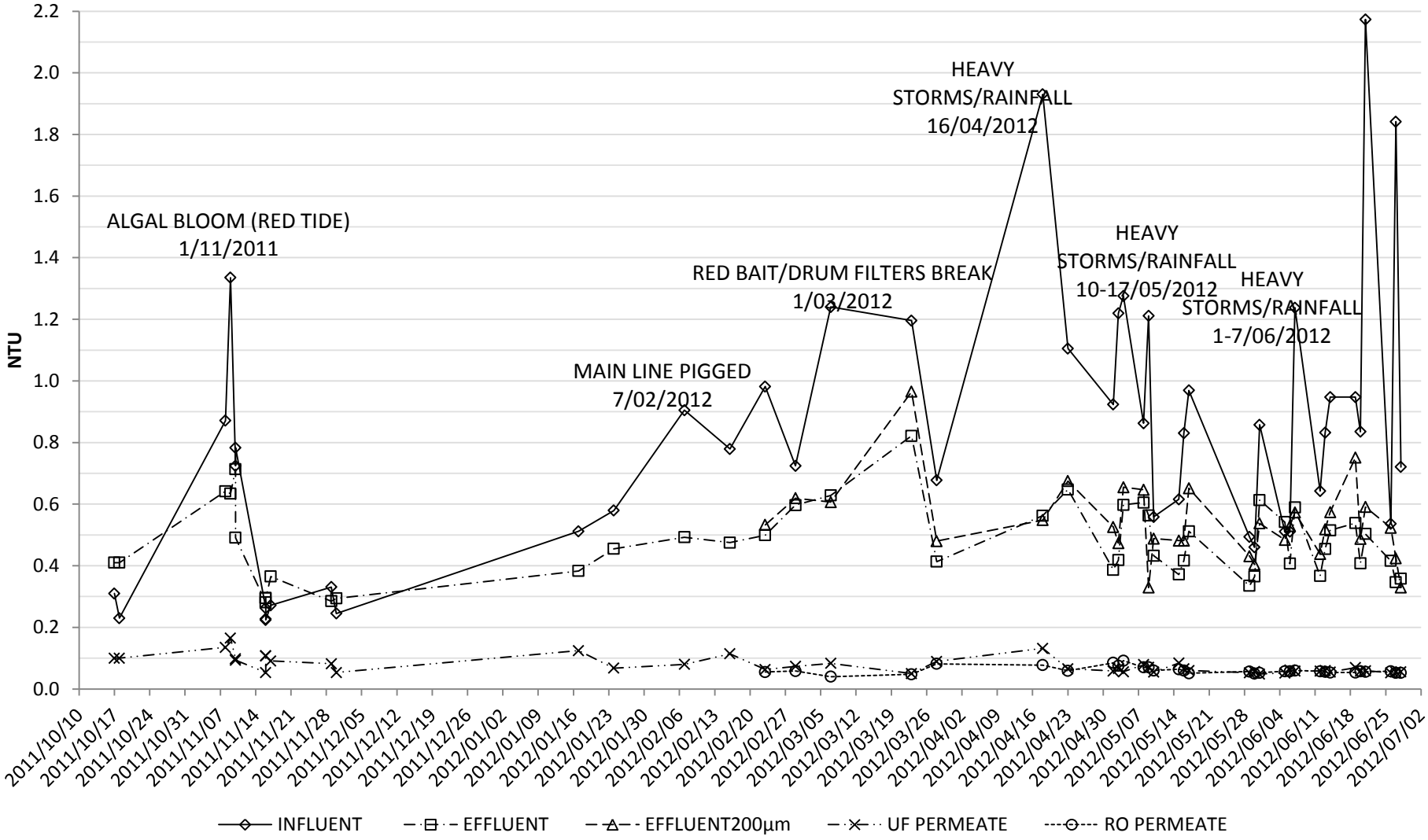

Figure 5.2.7 *– Influent, effluent, effluent$_{200\mu m}$, UF feed, UF permeate and RO feed/permeate/concentrate stream turbidity*

5.2.8 Modified Fouling Index

The trends of influent and effluent $MFI_{0.45}$ are presented in Figure 5.2.8 with error bars indicating the standard error of the measurements. The statistics of the $MFI_{0.45}$ values measured are summarised in Table 5.2.8.

The $MFI_{0.45}$ values for the effluent were, without exceptions, higher than that of the influent over the entire period measured from November 2011 to June 2012. The influent $MFI_{0.45}$ ranged from 13 – 96 s/litre^2 with a mean value if 29 s/litre^2. The effluent $MFI_{0.45}$ ranged from 14 – 161 s/litre^2 with a mean value of 48 s/litre^2. This means there was a 65.8% increase in the mean $MFI_{0.45}$ measured for the influent sea water stream as it flows through the abalone tanks to become the effluent stream. This is a significant increase and will without a doubt have an effect on the UF pilot unit performance.

The fact that the turbidity of the effluent as compared to the influent decreased over the same period indicates the incapability of turbidity alone to predict the fouling potential of feed waters to SWRO desalination plants. The foulants causing the increased $MFI_{0.45}$ values in the effluent stream are therefore too small to be picked up in turbidity readings. The $MFI_{0.45}$ is linear with regards to foulant concentration and gives a more accurate indication of the filterability of the water.

Table 5.2.8 *– Influent and effluent $MFI_{0.45}$ statistics*

$MFI_{0.45}$	**INFLUENT MFI (s/litre^2)**	**EFFLUENT MFI (s/litre^2)**
Mean	*29*	*48*
Standard Error	*3*	*5*
Median	*25*	*42*
Standard Deviation	*17*	*26*
Sample Variance	*282*	*698*
Kurtosis	*7*	*10*
Skewness	*2*	*3*
Range	*13 - 96*	*14 - 161*
Confidence Level (95.0%)	*6*	*9*

Due to the linear relationship between $MFI_{0.45}$ and foulants present in the water it is clear that on the micro-filtration scale the amount of foulant in the effluent from the abalone tanks are slightly higher than that in the influent and that this water does pose a slightly higher risk of fouling on the ultra-filtration membranes but not on the RO according to the equivalent $MFI_{0.45}$ reduction by UF and the guideline of 0.6 - 2.4 s/litre^2 (Alhadidi *et al.* 2012). Referring back to die MFI trends when analysing the UF performance will be informative.

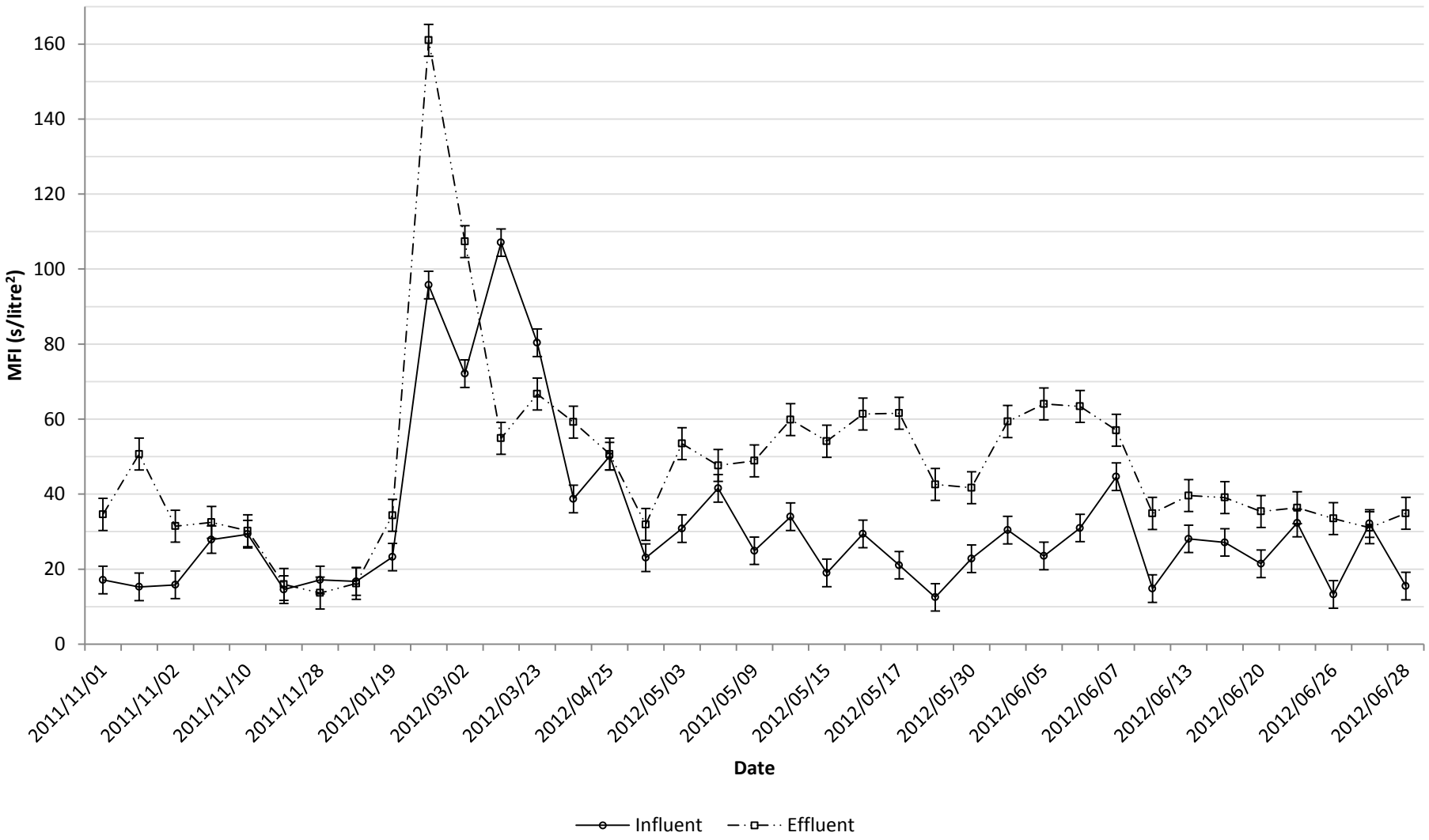

Figure 5.2.8 *– Influent and effluent* $MFI_{0.45}$

5.3 ON-SITE PILOT STUDY

The SWRO desalination pilot plant consisted of the UF pilot unit and the RO pilot unit. Although the performance of these units are discussed separately, it is important to note that they form an integrated unit and cross referencing between the water characterisation, UF performance and the RO performance results will establish a proposed desalination strategy for abalone effluent water.

5.3.1 Ultrafiltration

The UF unit pilot study forming part of the SWRO desalination pilot plant study was divided into three experimental periods with one UF membrane (element A) and two experimental periods with another UF membrane (element B). The data graphs showing the trends in actual flux, feed water temperature and trans membrane pressure (TMP) are presented here followed by the graphs representing temperature corrected flux (flux corrected to 25°C) versus TMP for comparison purposes between the different experimental runs conveyed at different feed temperatures. These figures along with the trends observed during the water characterisation will determine the feasibility and viability of using UF as pre-treatment for the RO pilot unit. The operational parameters which should be considered when designing a commercial scale SWRO desalination plant on a typical South African abalone farm are also determined.

Table 5.3.1 presents the start-up operating parameters for each experimental period (from Table 4.3.1.1.2).

Table 5.3.1 *– UF experimental period start-up operating parameters*

PARAMETER	**ELEMENT A**			**ELEMENT B**	
	PERIOD 1 ***8/02/2012 - 13/03/2012***	**PERIOD 2** ***20/03/2012 - 03/04/2012***	**PERIOD 3** ***17/04/2012 - 17/05/2012***	**PERIOD 1** ***22/05/2012 - 15/06/2012***	**PERIOD 2** ***19/06/2012 - 09/07/2012***
Recovery (%)	*81*	*78*	*66*	*80*	*71*
Permeate Flux (LMH)	*79*	*83*	*40*	*60*	*29*
Backwash Flux (LMH)	*333*	*258*	*387*	*360*	*286*
Filter Duration(s)	*720*	*900*	*1500*	*1200*	*1200*
Backwash Duration (s)	*40*	*80*	*80*	*50*	*50*
CEB Interval (h)	*24*	*24*	*24*	*24*	*24*
Flocculation (mg/litre)	*3*	*0*	*0*	*0*	*3*

5.3.1.1 Element A

The trends of UF instantaneous flux, TMP and feed temperature are presented in Figure 5.3.1.1a.

The UF pilot plant was started on 8 February 2012 with initial operating parameters as stated in Table 5.3.1. The first run with element A was for a period of three weeks from 9 February to 13 March during which the operation of the element with direct coagulation at 3 mg/litre (as Fe^{3+}) was investigated. On 29 February, after concerns about the proper hydrolysation of the coagulant, the inlet dosing valve was moved to a position in-line before the feed pump to ensure proper mixing and hydrolysation of the iron(III)chloride through the pump. This in turn led to failure of the dosing inlet valve which caused a large amount of coagulant to be deposited on the UF membrane – fouling it. CEB soaking times were increased at this stage and EDTA added in an attempt to remove the iron(III)chloride fouling – this recovered an unsatisfactory amount of the membrane performance and on 13 March the membrane was removed for to undergo CIP.

The UF pilot plant was re-started on the 20 March 2012 with element A after CIP with initial operating parameters as stated in Table 5.3.1. During the second run, the coagulation was removed in order to prevent a repetition of the coagulant fouling, but also to investigate the membrane performance without coagulation. On 3 April the inlet pump to the buffer tank feeding the UF failed and the entire plant had to be shut down, the UF and RO pilots were rinsed with RO permeate and filled with a 1 wt% SMBS solution to preserve the membranes whilst the inlet pump was replaced.

After replacing the inlet pump the UF pilot plant was re-started for the third and final run with element A on 17 April 2012 after rinsing and storage with initial operating parameters as stated in Table 5.3.1. After initial fluctuations in membrane flux the membrane returns to a stable performance similar to that observed during the second run. Fortunately the third run is completed without any disruptive event and is stopped on 16 May. A stable performance was established at which it can operate with the quality of feed water at the time.

The trends for UF temperature corrected flux (specific flux), TMP and inlet temperature are presented in Figure 5.3.1.1b.

Element A: Experimental Period 1

During the first week of start-up, with a weekend in between, (8 – 17 February) the effluent water turbidity was 0.48 – 0.49 NTU although the influent water quality deteriorated due to the main lines on the abalone farm being ‘pigged’; no $MFI_{0.45}$ measurements were taken

during this time. A significant decrease in specific flux of the UF membrane from approximately 110 LMH to 80 LMH (27%) was observed during the first few days after start-up. Average actual recovery during this week was 78%.

During the second week of operation (20 – 24 February) the effluent turbidity was 0.53 NTU on the only day measured and the $MFI_{0.45}$ reading taken, 161 s/litre^2, was very high but most likely only a spike since no sudden clear deterioration in the UF performance was observed. The specific flux ranged between 56 and 87 LMH (70 LMH average) with the average TMP equal to 0.35 bar, and average recovery 78%.

In the third week of operation (27 February – 2 March) the flux ranged between 57 and 74 LMH at an average TMP of 0.37 bar until the coagulant fouling incident occurred after which the flux dropped drastically to 27 LMH and the TMP started increasing rapidly. The turbidity measured during this week was 0.62 NTU; $MFI_{0.45}$ was not measured. The average recovery was 75%.

In the fourth week (5 – 9 March) of operation, after extended CEB washes, the performance of the membrane could not be recovered and it operated at a specific flux ranging between 40 and 58 LMH at an average TMP of 0.80 bar. The effluent turbidity was measured once during this week at 0.61 NTU and the $MFI_{0.45}$ at 107 s/litre^2. The average recovery was 73%.

Element A: Experimental Period 2

After CIP the UF pilot unit was re-started without flocculation and coagulation. On 20 March, during the first week of operation after the re-start, performance initially increased significantly but quickly returned to its previous state. This can be ascribed to swelling of the membrane fibres during CIP, increasing its permeability, and the subsequent recompression after start-up leading to the drop in flux.

During the second week (26 – 30 March) the specific flux ranged from 42 – 60 LMH with an average TMP of 0.50 bar. The effluent turbidity decreased during this period from 0.97 to 0.48 NTU with no $MFI_{0.45}$ reading measured during this week. The sudden increase in TMP can be attributed to CEB not being performed every 24hours during the previous weekend. The average recovery was 62% during that week.

In the third week of operation (2 – 6 April) a sudden increase in TMP to 0.70 bar was observed. An increase in TMP and/or a drop in flux rate were repeatedly observed subsequently to weekends when CEB was not performed every 24 hours. Specific flux

during this week was almost unchanged in comparison to the previous week at 52 – 54 LMH and the actual average recovery was increased slightly to 63%.

Element A: Experimental Period 3

After a RO permeate rinse and a week of soaking in a SMBS and EDTA storage solution the UF was re-started on 17 April without flocculation and coagulation. After initial fluctuation in TMP during that first week after start-up the UF was operated at a steady specific flux ranging between 54 and 58 LMH at an average TMP of 0.55 bar. During this time the effluent turbidity was 0.55 NTU and MFI fluctuated at an average value of 59 s/litre^2. The average recovery was 67%.

In the second week (23 – 27 April) after an initial drop in flux after the weekend, the specific flux remained between 59 and 66 LMH at an average TMP of 0.65 bar and average recovery of 68%. The effluent turbidity during this week was 0.68 NTU and $MFI_{0.45}$ was 51 s/litre^2.

During the third week (30 April – 4 May) the measured turbidity ranged between 0.47 and 0.66 NTU and ranged $MFI_{0.45}$ between 32 and 53 s/litre^2. After an initial decrease in flux over the weekend, the flux in the third week ranged between 52 and 55 LMH at a TMP of 0.55 bar and an average recovery of 67%.

In week four of this run (7-11 May), turbidity ranged between 0.33 and 0.65 NTU and $MFI_{0.45}$ ranged between 47 and 60 s/litre^2. A slight decrease in flux was observed directly after the weekend after which the flux ranged between 45 and 55 LMH at a TMP of 0.57 bar and an average recovery of 67%.

In the fifth and final week of this run (14 – 18 May) after a slight decrease in flux following the weekend, the flux ranged between 45 and 55 LMH at a TMP of 0.61 bar which was slightly higher than that for the previous week. The actual recovery was 67%; turbidity ranged between 0.58 and 0.65 NTU and $MFI_{0.45}$ ranged between 54 and 62 s/litre^2.

5.3.1.2 Important observations (Element A)

Persson *et al.* (1995) conveyed a study on membrane compaction and its influence on ultrafiltration water permeability. They found a two hour filtration at TMP of 300 kPa resulted in lowered fluxes of as much as 18% for PESM UF membranes such as used in this study. They also showed that PESM membranes are compressed more at lower pressures and continued to be sensitive for compression when pressure was increased once compared to other membranes. PESM membranes showed flux drop at pressures as low as 50 kPa. The initial decrease in the specific flux of the UF membrane, from approximately 110 LMH to

80 LMH (27%), directly after start-up, was therefore largely attributed to compaction of the membranes and CEB not being performed every 24 hours during the weekend. Regular CEB – at least every 24 hours – is fundamental to the stable operation of a UF membrane in these conditions. This was clear from the detrimental effect of not performing CEBs during weekends on the UF performance throughout the entire pilot study on element A. Decreases in flux and increases in TMP was observed after every weekend during which regular CEB was not performed.

During the first run on element A the membrane performance, after initial membrane compaction and flux loss, was fine. Coagulant was dosed directly at 3 mg/litre (as Fe^{3+}) before the membrane although water quality was high (NTU ~ 0.65, DOC < 1 mg/litre) with the exception of a spike in $MFI_{0.45}$. An average specific flux of 66 LMH (recovery ~ 78%) was achieved while TMP increased with only 0.02 bar (0.35 – 0.37 bar) during this time. If not for the unfortunate coagulant fouling one would be inclined to believe that the membrane would have stabilised at these performance values, if the feed water quality remained the same. During the second and third runs on element A, the membrane performance worsened, although the water quality remained relatively high (NTU ~ 1, DOC <1 mg/litre, $MFI_{0.45}$ ~ 58 s/litre^2). The average specific flux dropped to 54 LMH (recovery ~ 67%) at a TMP of 0.59 bar. The drop in TMP between every CEB was also much more significant in the second and third runs (ΔTMP ~ 0.4 bar) than in the first run (ΔTMP ~ 0.1 bar). This could have been caused either by the removal of the direct coagulation during these runs or the coagulant overdosing caused permanent damage/fouling to the UF membrane leading to a reduced flux and increased TMP values. This question was answered by the UF pilot study with element B where the effect of coagulation on membrane performance was tested.

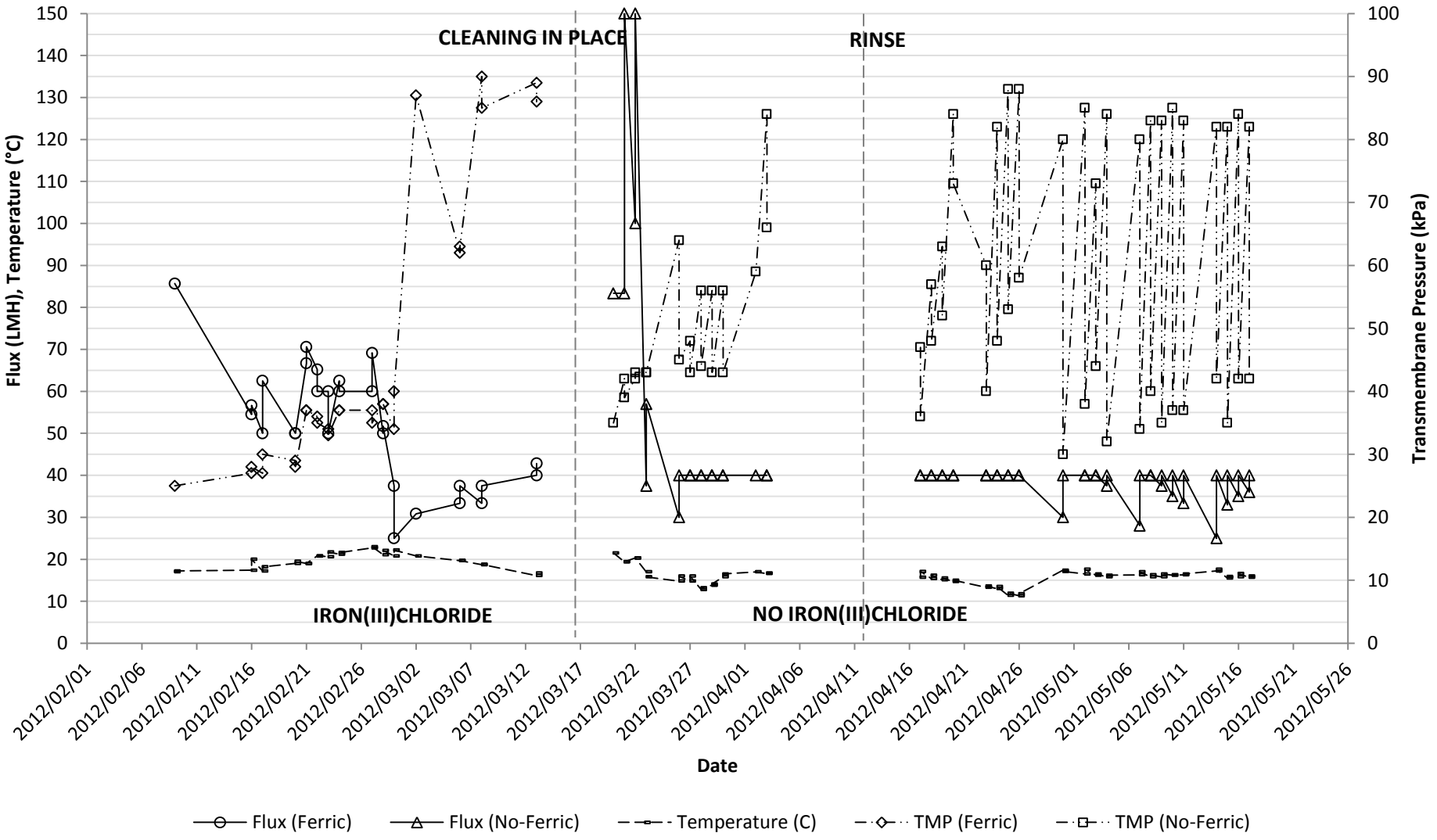

Figure 5.3.1.1a *– Ultrafiltration flux, temperature and TMP*

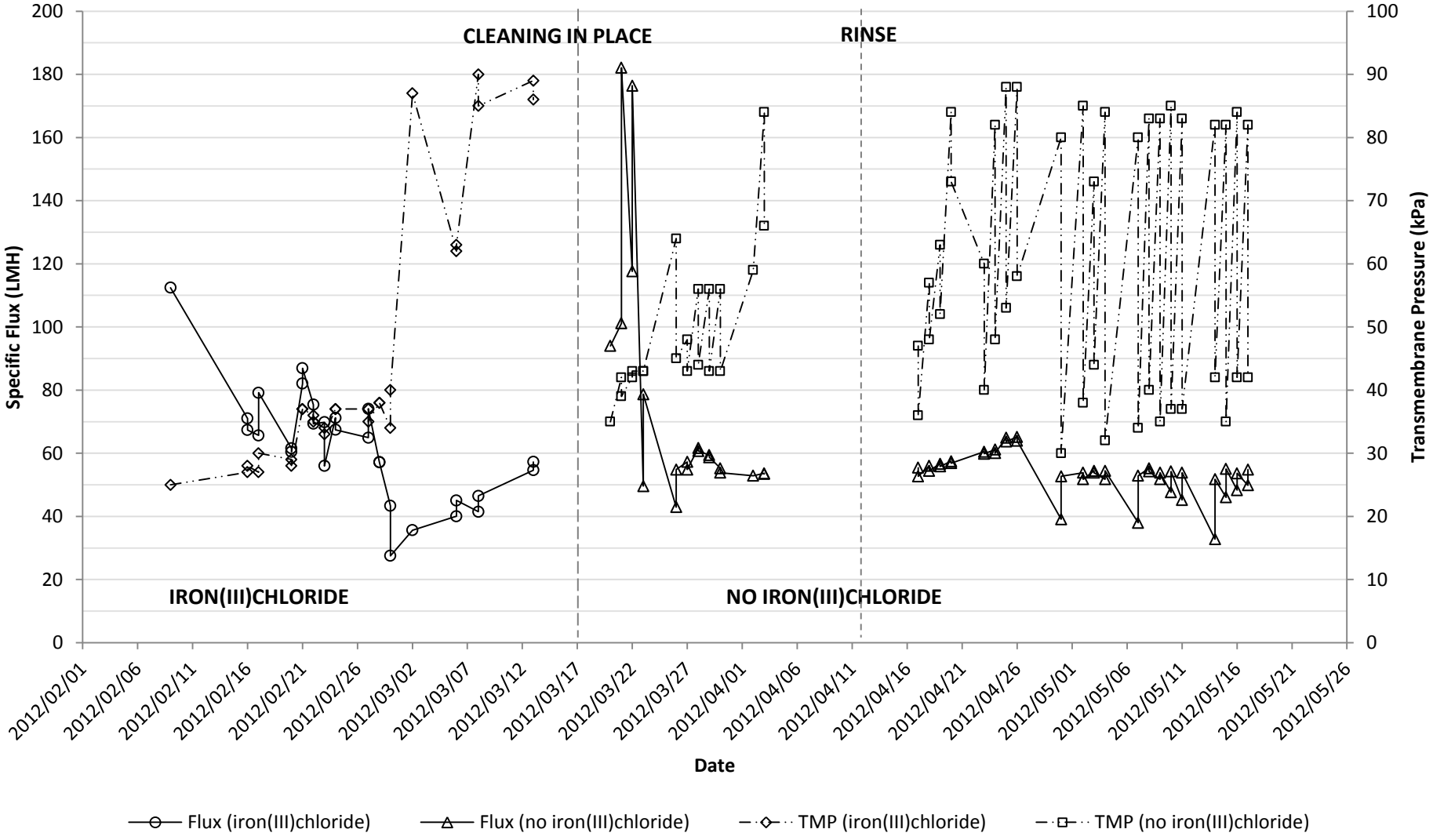

Figure 5.3.1.1b *– Ultrafiltration specific flux and TMP*

5.3.1.3 Element B

The trends for UF instantaneous flux, TMP and inlet temperature are presented in Figure 5.3.1.3a.

The UF pilot plant was started on 22 May 2012 with a new membrane. Initial operating parameters were as presented in Table 5.3.1. The first experimental period with the new membrane, element B, was done from 22 May to 15 June without any major incidents. Proper UF performance data were collected during these four weeks after which the UF was stopped to start the second run on element B.

The UF pilot plant was re-started on the 19 June 2012 with the same membrane and the operating parameters as summarised in Table 5.3.1. The second experimental period with element B was done for a period of 5 weeks from 19 June to 9 July during which the operation of the element with coagulation at 3 mg/litre (as Fe^{3+}) was looked into. An in-line venturi was employed for mixing and hydrolysation of the coagulant followed by a pipe flocculator. Good UF performance data were collected during these five weeks.

The trends for UF specific flux, TMP and inlet temperature are presented in Figure 5.3.1.3b.

Element B: Experimental Period 1

In the first week (22 – 25 May) a specific flux of 79 – 84 LMH at an average TMP of 0.23 bar was observed from the start-up with the new membrane at an average recovery of 81%.

In the second week (28 May – 1 June) the average TMP was 0.36bar for specific flux ranging between 45 and 80 LMH at an average recovery rate of 79%; the effluent turbidity during this period ranged from 0.43 to 0.54 NTU while the $MFI_{0.45}$ measurements ranged between 42 and 59 s/litre^2.

In the third week (4 – 8 June) the average TMP increased to 0.55 bar with specific flux ranging between 30 and 60 LMH; the effluent turbidity during this period ranged from 0.48 – 0.57 NTU whereas the $MFI_{0.45}$ measurements ranged between 39 and 64 s/litre^2. The average actual recovery during this week was 73%.

In the fourth week (11 – 15 June) the average TMP increased to 0.76 bar with specific flux ranging between 30 and 55 LMH with an average recovery of 70%. The effluent turbidity during this period ranged from 0.44 to 0.57 NTU whereas the $MFI_{0.45}$ measurements ranged from 34 to 39 s/litre^2.

Element B: Experimental Period 2

In the first week after starting coagulation dosing at 3 mg/litre Fe^{3+} a significant drop in required TMP was observed. During the first week after start-up (18 – 22 June) the average TMP decreased from 0.91 to 0.13 bar for a specific flux that ranged between 38 and 44 LMH at an average actual recovery of 68%. The effluent turbidity during this period ranged from 0.49 to 0.75 NTU whereas the $MFI_{0.45}$ measurements ranged between 33 and 36 s/litre^2.

During the next two weeks (25 June – 6 July) the average TMP was 0.11 bar for a specific flux that ranged between 38 and 44 LMH. The effluent turbidity during this period ranged from 0.33 – 0.52 NTU whereas the $MFI_{0.45}$ measurements ranged between 31 and 35 s/litre^2. The average actual recovery during these two weeks is 65%.

5.3.1.4 Important observations (Element B)

The lessons learnt with the first element were applied during the pilot study on the second membrane. The first change was to reduce the actual flux at which the membrane was started to 60 LMH – since the high flux at which element A was commissioned was clearly too high. Also the filtration time was increased to 1200 seconds (from 720 seconds) to compensate for the lowered flux rate. This in turn led to a smaller initial reduction in flux due to the compaction phenomenon.

During the first run on element B the membrane performance gradually declined on a weekly base. Every week there were significant decreases in membrane performance while the water quality remained relatively constant throughout that period. Effluent turbidity remained stable whereas $MFI_{0.45}$ actually decreased throughout this period (NTU <0.6, $MFI_{0.45}$ ~ 49 s/litre^2, DOC <1 mg/litre). This re-iterates the importance of regular CEB (at least every 24 hours). The membrane finally seemed to reach stability as the TMP flattened out and flux remained stable during the final week of experimental period 1 for element B. The average specific flux at which the membrane stabilised was 45 LMH at a TMP of 0.76 bar and average recovery of 70%. This was comparable to the 54 LMH and recovery of 67% at a TMP of 0.59 bar of element A without flocculation and with similar feed water (~ 1 NTU, DOC < 1 mg/litre, $MFI_{0.45}$ ~ 58 s/litre^2). The temperature differences between these runs were compensated for by using specific flux. The UF should therefore be able to operate at a specific flux ranging from between 45 to 55 LMH at a recovery ranging between 60 and 75% at a TMP between 0.59 and 0.76 bar without coagulation.

During the second run on element B, coagulant was dosed at 3 mg/litre (as Fe^{3+}) and hydrolysed by means of an in-line venturi with flocculation occurring in a short pipe flocculator. The water quality was slightly better than during the first run (NTU ~ 0.52,

$MFI_{0.45}$ ~ 34 s/litre^2, DOC < 1 mg/litre). The effect of the flocculation was evident in the significant reduction in average TMP from 0.76 to 0.11 bar at a slightly lower specific flux rate of 41 LMH and average recovery of 68%. Considering the fact that for UF membranes there was a linear relationship between flux and TMP this was comparable to the average specific flux of 66 LMH and recovery of 78% at 0.36 bar TMP for element A with similar quality feed water (NTU ~ 0.65, DOC <1 mg/litre). The UF should therefore be able to operate at a flux ranging from 40 – 65 LMH, at a recovery ranging between 65 and 70% and a TMP between 0.11 and 0.36 bar with in-line coagulation and flocculation at a concentration of 3 mg/litre (as Fe^{3+}).

Proper coagulation therefore flocculated the finer particles that could enter the pores of the UF membrane where it could not easily be removed by means of CEB. Conglomeration of the particles prevented them from entering the pores of the UF membrane, making it easier to remove and therefore improving the recovering effect of daily CEBs even when not applied every 24 hours. The deterioration of the membrane performance was significantly less with flocculation and coagulation than when no coagulant was dosed. This indicated that although the turbidity and DOC of the feed water was low (NTU <1, DOC <1 mg/litre) and there were no significant changes in the $MFI_{0.45}$, which can be correlated to the behaviour of the UF membrane, there might have been substances passing through the 0.45 µm $MFI_{0.45}$ membranes that were rejected by the UF membranes. It was proven that these substances can be removed by means of proper coagulation and flocculation.

Note that the UF plant was not optimised since abalone farm effluent flow rates was significantly higher than the UF feed requirements as would be the case for most medium sized UF plants on large abalone farms.

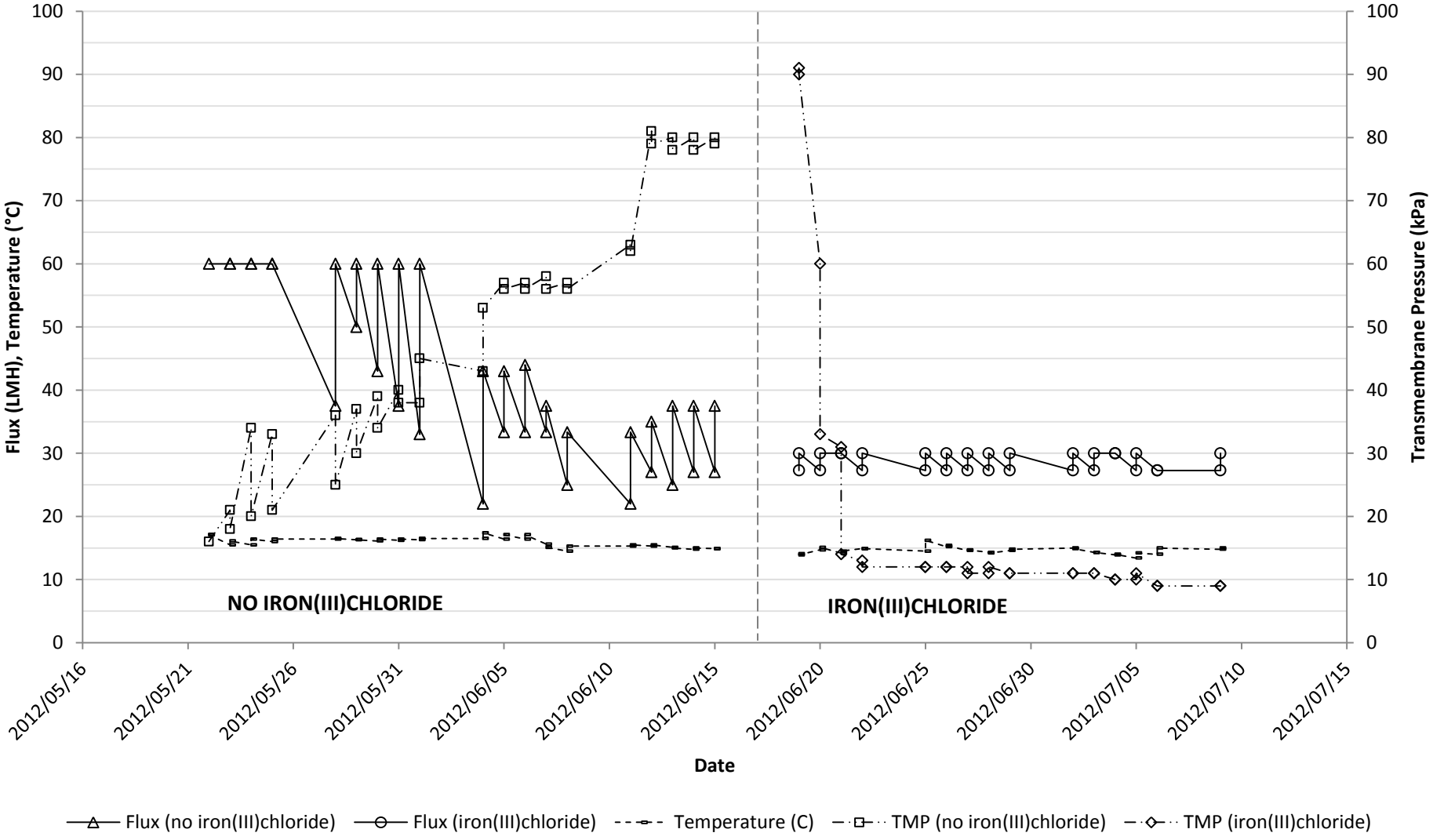

Figure 5.3.1.3a *– Ultrafiltration flux, temperature and TMP*

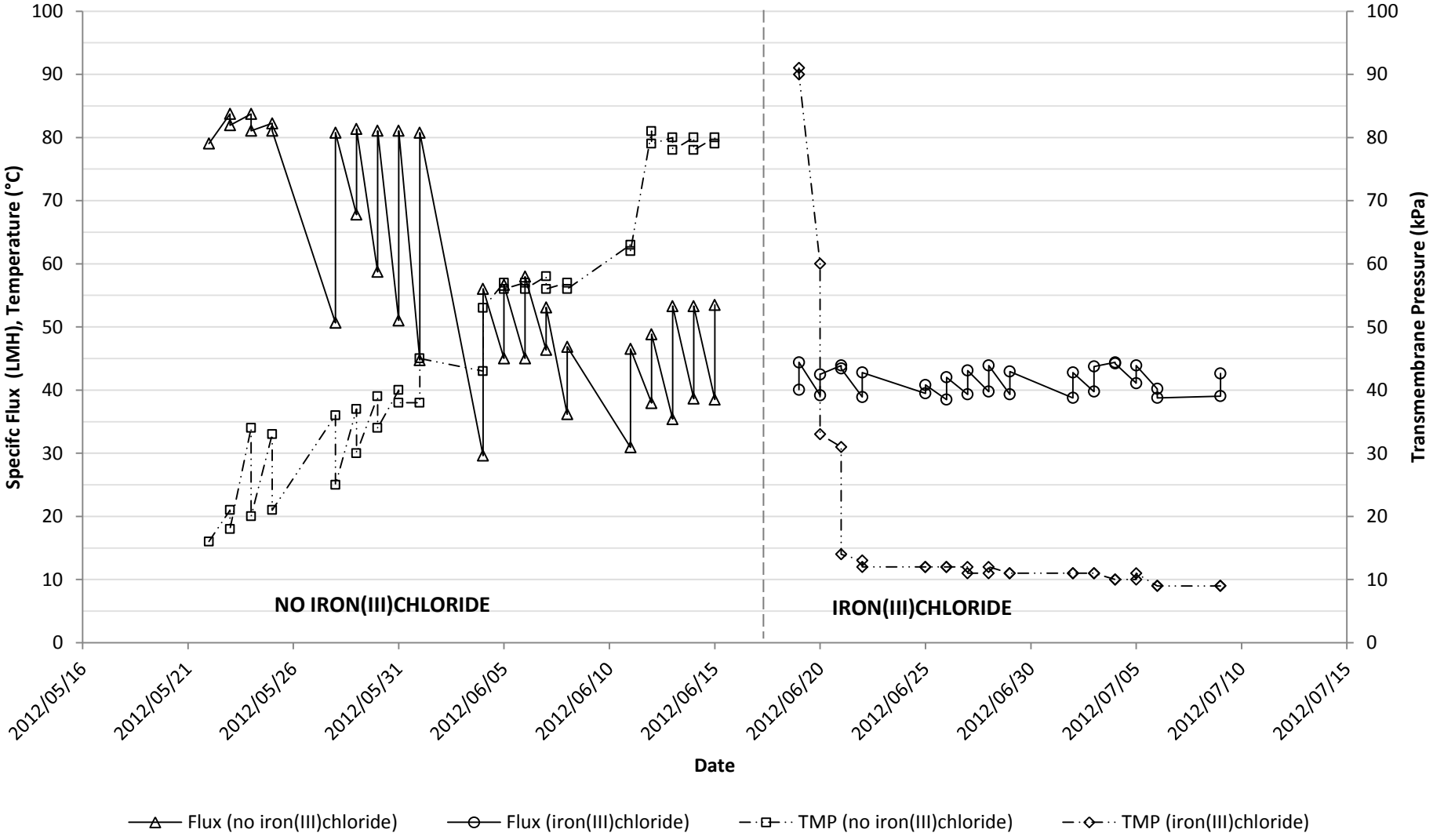

Figure 5.3.1.3b *– Ultrafiltration specific flux and TMP*

5.3.2 Reverse Osmosis

The RO pilot study forming part of the SWRO desalination pilot plant, was divided into three experimental periods, all performed with the same DOW FILMTEC™ SW30-2540 Polyamide Thin-Film Composite membrane. A graph showing trends in normalised flux (corrected for temperature and pressure) with feed TDS and a graph presenting the trends in salt rejection rate with feed water temperature are presented here.

ROSA (Reverse Osmosis System Analysis) design software provided by DOW Water & Process Solutions was used to simulate the 'feed-and-bleed' RO system using a SW30-2540 thin film composite (TFC) polyamide membrane to predict the clean or new membrane performance. The design parameters specified in this simulation were as measured at start-up of the RO pilot plant. The feed pressure (60 bar), the recycle rate (250 litre/h) the feed flow rate (59 litre/h) and the feed TDS (33 271 mg/litre) were specified; the programme then estimated the permeate and concentrate flow rates.

A flow factor can be specified in ROSA. The flow factor (FF) in ROSA is a value used to calculate the system feed pressure under certain conditions or at a certain age. The FF is defined as the fraction of the water permeability of the membrane relative to a membrane with nominal flow specifications. It allows calculation of the remaining flow performance of a membrane system considering the effect of reversible and irreversible fouling, aging effects due to temperature, pressure and operation time, and a safety margin.

In this study the feed pressure was not required, but rather a baseline of the predicted membrane performance at start-up conditions namely; 28°C feed temperature, 56 bar feed pressure and 33 721 mg/litre feed TDS. With a FF of 1.0 the permeate flow was calculated for a system with the membrane element performing according to the published nominal flow specifications. The predicted permeate flux rate at these conditions was 10.16 LMH; this flow predicted rate was slightly higher than the actual initial permeate flow rate. This could be expected as the simulation used a NaCl composition balance and did not consider the exact composition of the water – it was only an estimate, but it did serve as an indication of the integrity of the new membrane. This estimate (with FF = 1.0) did not consider either compaction or fouling of the membrane. Margins for the typical decrease in flux due to compaction and fouling could therefore be set up in order to determine whether the membrane performed within these limits.

The application of high hydrostatic pressures to RO membranes causes a reduction in membrane permeability due to compaction. Under pressure the polymers are slightly reorganized and the structure is changed, resulting in a lowered porosity, increased

membrane resistance and eventually lowered flux. The compaction problem in polyamide TFC RO membranes presents itself mainly due to compaction of the thick porous polysulfone support layer rather than the thin compact polyamide layer. Generally the flux decline in sea water desalination is as high as 30 – 40% due to compaction *(Pendergast et al.* 2010). If a conservative flux decline of 20%, due to compaction, is applied the predicted normalised flux the normalised membrane flux after compaction should be approximately 8.13 LMH.

As discussed in the section 3.5.5 of this dissertation the fouling of membrane surfaces manifests itself in performance decline; lower permeate flow rate and/or higher solute passage. It is recommended that membranes be cleaned when the normalised permeate flow decreases 10% or more to prevent irreversible fouling which cannot be removed by means of CIP. This drop in permeate flow due to fouling is expected to occur after the initial compaction of the TFC polyamide RO membrane. A further reduction of 10% in flux will set the flux limit to prevent permanent fouling at 7.31 LMH.

Normalisation with reference to the initial system performance is useful to indicate any performance changes between day one and the actual date. The data from the pilot plant were therefore normalised to the initial system parameters and performance. Figure 5.3.2.1 presents the trends in permeate flux normalised to the start-up conditions namely; a temperature of 28°C, feed pressure of 56 bar, and feed TDS of 33 271 mg/L for the duration of the pilot study.

Table 5.3.2 presents the start-up operating parameters for each experimental period (from Table 4.3 2).

Table 5.3.2 *– RO experimental period start-up operating parameters*

PARAMETER	17/02/2012 - 13/03/2012 PERIOD 1	20/03/2012 - 03/04/2012 PERIOD 2 (A)	17/04/2012 - 17/05/2012 PERIOD 2 (B)	24/05/2012 - 02/07/2012 PERIOD 3	04/07/2012 - 09/07/2012 PERIOD 4
Feed Pressure (bar)	*56.5*	*57.0*	*58.0*	*59.0*	*60.0*
Recovery Single Pass (%)	*8.0*	*8.1*	*8.1*	*8.2*	*8.2*
Recovery Overall (%)	*42.4*	*42.4*	*42.4*	*43.1*	*43.9*
Permeate Flux (LMH)	*8.9*	*8.9*	*8.9*	*9.2*	*9.0*
Feed (litre/h)	*59.0*	*59.0*	*59.0*	*59.9*	*57.7*
Permeate (litre/h)	*25.0*	*25.0*	*25.0*	*25.8*	*25.3*
Concentrate (litre/h)	*34.0*	*34.0*	*34.0*	*34.1*	*32.4*
Recycle (litre/h)	*255.1*	*249.6*	*249.6*	*254.7*	*250.9*
Antiscalant (mg/litre)	*12*	*12*	*12*	*11*	*11*
DBNPA (mg/litre weekly)	*30*	*30*	*30*	*30*	*30*

5.3.2.1 Reverse Osmosis: Experimental Period 1

The RO pilot plant was started on 17 February 2012 with the initial operating parameters as summarised in Table 5.3.2.

As with any new plant, one goes through a learning curve regarding the operation of an SWRO pilot plant such as used in this study. The result was that the initial operation and data collection of the RO pilot plant was not as smooth and accurate as those taken after the first week or two of operation. In the end most of these problems were resolved.

The normalised permeate flux through the membrane dropped to approximately 80% of the initial flux within the first week after commissioning due to the compaction of the membrane. Slight changes in feed TDS were amplified due to the recycle stream built into the 'feed-and-bleed' system causing some spikes in the feed TDS to the membrane. The spikes in feed TDS to the membrane then in turn caused spikes in the permeate flux of the membrane.

An increase in feed TDS:

- decreases permeate flow rate due to increased osmotic pressure difference,
- increases permeate salt flow due to increased concentration difference and therefore
- also increases permeate salinity.

A decrease in feed TDS causes the exact opposite to occur.

The UF membrane iron(III)chloride fouling incident may also have caused fouling on the RO membrane. It is most likely that some of the iron(III)chloride migrated through the UF membrane and into the UF permeate which feeds to the RO pilot unit. This is evident from the significant decrease in the RO permeate flux, although the feed TDS decreased during this time. This caused the permeate flux to drop below the 10% fouling limit and it was decided to stop the RO unit on 13 March 2012 to CIP the RO membrane (CIP_1).

5.3.2.2 Reverse Osmosis: Experimental Period 2 (A and B)

The RO pilot plant was re-started on 23 March 2012 with the initial operating parameters as shown in Table 5.3.2. The RO membrane performance recovered very well thanks to the CIP; with initial permeate flow rates exceeding the 20% compaction limit at start-up after the CIP. This indicates that either the initial decrease in flux of approximately 20% cannot completely be ascribed to the compaction or that the CIP causes swelling of the membrane leading to the increased permeability and flux rate above this limit. The latter is more likely since the flux rate returned rather speedily to the 20% compaction limit, whereas the feed TDS remained similar to that observed during experimental period 1. Fluctuations in feed

TDS clearly influenced the normalised permeate flux rate – flux decreased with an increase in TDS and vice versa. On 3 April the inlet pump to the buffer tank feeding the UF pilot unit broke and the entire plant had to be shut down. The UF and RO pilot units were both rinsed with RO permeate and stored in a 1 wt% SMBS membrane preservation solution whilst the inlet pump was being replaced.

After replacing the inlet pump feeding the SWRO desalination plant buffer tank the RO pilot plant is re-started on 17 April 2012, with the initial operating parameters as summarised in Table 5.3.2. The normalised permeate flux initially seemed to be lower than just before the plant was switched of. The normalised flux however slowly returned to the 20% compaction limit. The membrane seemed to have stabilised with no significant or irrecoverable fouling occurring.

On the 17 May 2012 it is decided to CIP the membrane (CIP_2) to establish whether the performance of the membrane could be returned to that observed after the first CIP (CIP_1) producing a normalised flux of 8.87 LMH or higher.

5.3.2.3 Reverse Osmosis: Experimental Period 3

After the second CIP (CIP_2) the RO pilot plant was re-started on 24 May 2012 with the initial operating parameters as presented in Table 5.3.2. The CIP recovered some of the performance of the membrane, but only to just above the 20% compaction limit – this makes sense – since compaction induces permanent loss in permeate flux rate. During this run the capturing of data was much improved compared to the first run. The membrane showed a steady but slow decrease in normalised permeate flux due to fouling during the next five weeks. The membrane produced a satisfactory performance and stabilised during this run.

The membrane was given a final CIP (CIP_3) at the end of the third experimental run to determine whether the fouling occurring during those five weeks was reversible or irreversible and also to what degree the membrane performance could be restored.

5.3.2.3 Reverse Osmosis: Experimental Period 4

The RO pilot plant was re-started finally on 2 July 2012 with the initial operating parameters as summarised in Table 5.3.2. From the initial operating parameters it was clear that the fouling which occurred during those last 5 to 6 weeks was reversible and could be removed by means of a proper CIP operation. A CIP frequency of 5 to 6 weeks needs to be considered when designing a commercial scale SWRO desalination plant for these conditions.

5.3.2.4 RO Membrane Rejection

As discussed in section 3.5.2 of this dissertation, an increase in water temperature will increase both permeate water flow rate and salt flow rate and will therefore not affect permeate salinity. However, it is important to note that an increase in temperature decreases the viscosity of the water, requiring lower feed pressures to maintain the same flux which will then result in an increase in permeate salinity (if the flux remains the same). An increase in feed salinity will decrease permeate flow rate (due to increased osmotic pressure difference), increase permeate salt flow (due to increased concentration difference) and therefore increase permeate salinity. The migration of salt through the RO membrane is therefore affected by feed temperature and salinity.

Figure 5.3.2.2 presents the trends in salt rejection by the membrane for the entire duration of the pilot study showing an increasing salt rejection from 98.0 to 98.4% as the feed temperature decreased from 28.0 to 25.0°C as expected. This graph also shows that the integrity of the membrane was retained throughout the pilot study.

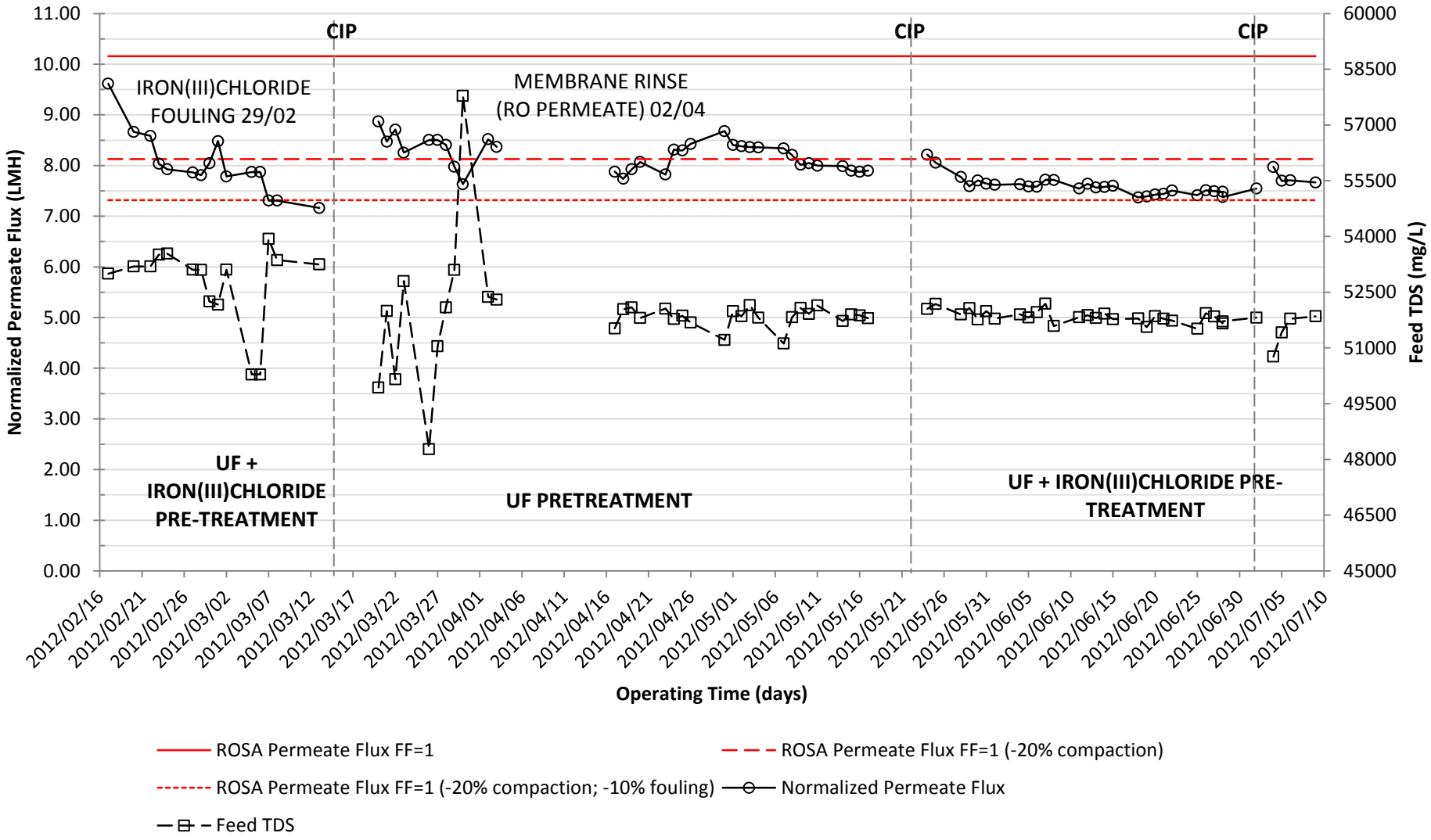

Figure 5.3.2.1 *– Normalised RO permeate flux and feed TDS*

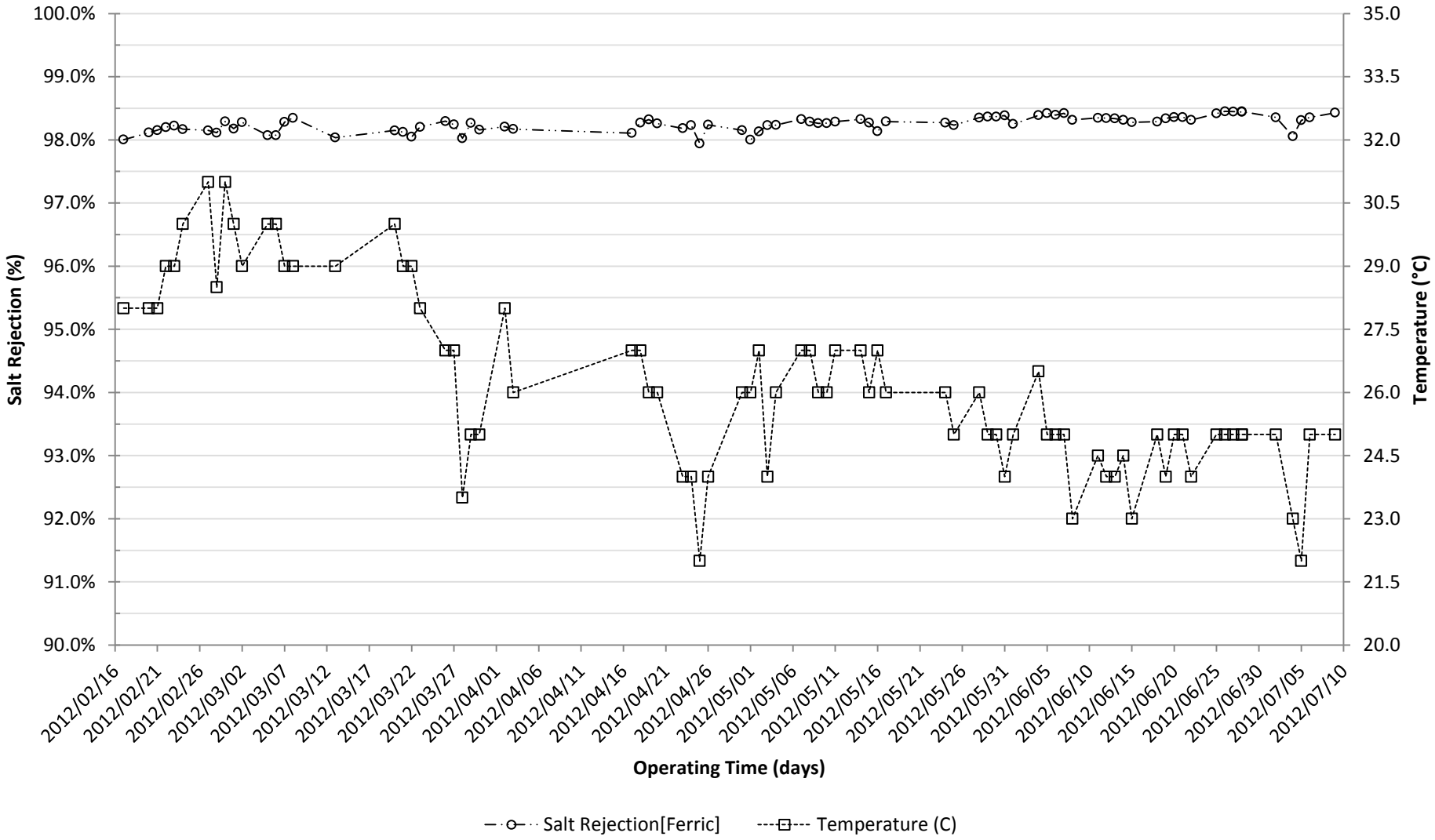

Figure 5.3.2.2 *– RO membrane salt rejection and membrane feed temperature*

5.3.2.5 RO Feed and Permeate Chemical Composition

Table 5.3.2.5 contains the results from the CSIR laboratory analyses for the feed and permeate streams of the RO pilot unit.

Table 5.3.2.5 *– RO feed and permeate streams: chemical composition*

		UF PERMEATE (RO FEED)			RO PERMEATE		
COMPONENT	**UNITS**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Potassium as K	*mg/litre*	*341*	*448*	*396*	*8*	*17*	*12*
Sodium as Na	*mg/litre*	*10 592*	*10 873*	*10749*	*251*	*273*	*259*
Calcium as Ca	*mg/litre*	*401*	*474*	*431*	*5*	*18*	*10*
Magnesium as Mg	*mg/litre*	*1247*	*1295*	*1268*	*14*	*16*	*15*
Ammonia as N	*mg/litre*	*0.005*	*0.038*	*0.023*	*0.005*	*0.038*	*0.022*
Sulphate as SO4	*mg/litre*	*2 836*	*2 948*	*2 875*	*34*	*37*	*35*
Chloride Cl	*mg/litre*	*19 500*	*21 100*	*20 200*	*428*	*441*	*436*
Alkalinity as CaCO3	*mg/litre*	*87*	*116*	*104*	*6*	*6*	*6*
Nitrate plus Nitrite as N	*mg/litre*	*0.045*	*135*	*84*	*6*	*45*	*29*
Nitrate as NO3	*mg/litre*	*0.041*	*0.127*	*0.079*	*0.005*	*0.041*	*0.027*
Nitrite as NO2	*mg/litre*	*0.004*	*0.008*	*0.004*	*0.001*	*0.004*	*0.002*
Ortho phosphate as P	*mg/litre*	*0.018*	*0.026*	*0.022*	*0.004*	*0.025*	*0.011*
Fluoride as F	*mg/litre*	*0.80*	*1.20*	*0.97*	*NA*	*NA*	*<0.1*
DOC	*mg/litre*	*NA*	*NA*	*<1*	*NA*	*NA*	*<1*
Specific Conductivity (25°C)	*µS/cm*	*50 000*	*56 000*	*52 333*	*1 440*	*1 580*	*1 513*
pH (20°C)		*7.5*	*7.8*	*7.6*	*5.8*	*6.1*	*6.0*
pHs (pHs @ 20°C)		*7.0*	*7.2*	*7.1*	*10.0*	*10.2*	*10.1*
Total Dissolved Solids (TDS)	*mg/litre*	*32 000*	*35 840*	*33 493*	*922*	*1 011*	*969*
Hardness as CaCO3	*mg/litre*	*6 194*	*6 380*	*6 298*	*70*	*108*	*86*
Sodium Adsorption Ratio (SAR)		*58.0*	*60.1*	*59.0*	*11.0*	*13.0*	*12.1*
Ryznar Index		*6.0*	*6.9*	*6.4*	*14.0*	*14.2*	*14.1*
Kjeldahl Nitrogen as N	*mg/litre*	*NA*	*NA*	*<1*	*NA*	*NA*	*<1*
Boron as B Dissolved	*mg/litre*	*-*	*-*	*4.3*	*-*	*-*	*0.2*
Silica as Si Dissolved	*mg/litre*	*-*	*-*	*0.2*	*-*	*-*	*0.1*
Strontium as Sr Dissolved	*mg/litre*	*-*	*-*	*7.5*	*-*	*-*	*0.1*
Bomide as Br Dissolved	*mg/litre*	*-*	*-*	*0.043*	*-*	*-*	*0.001*
Iron as Fe Dissolved	*mg/litre*	*-*	*-*	*0.026*	*-*	*-*	*<0.005*
Manganese as Mn Dissolved	*mg/litre*	*-*	*-*	*0.041*	*-*	*-*	*<0.001*

The feed stream referred to here is the overall feed stream (stream 6 in Figure 4.3.2) before the recycle stream is added. When considering the RO permeate quality it is important to remember that the RO 'feed-and-bleed' pilot plant simulated the final membrane in a full scale membrane bank. From here it is clear that, although the quality of the permeate does not adhere completely with the SANS 241:2011 drinking water standards (SABS Standards Division, 2011), it is on par with the typical quality produced by the last membrane in a full-

scale SWRO membrane bank. The TDS of the RO feed was reduced from 33 493 mg/litre to 969 mg/litre (97.1% removal). The metal compounds were also significantly reduced whereas ammonia is reduced by approximately 6.5%. These results compare well with the ROSA clean-membrane simulation predicting a TDS reduction from 33 271 mg/litre to 1 409 mg/litre (95.8% removal) at a feed pressure of 56 bar, overall recovery of 44.0% recovery.

5.4 SUMMARY

By characterising the influent and effluent sea water of forty abalone tanks on a typical South African abalone farm from 19 October 2011 to 26 April 2012 the following was verified:

- Temperature showed a mean increase from 15.5 to 15.6°C (0.1°C or 1.1%) from influent to effluent. Water temperatures ranged between 10 and 20°C with seasonal change.
- Specific conductivity showed a mean increase of 227 µS/cm (or 0.4%) from 52 784 µS/cm to 53 011 µS/cm.
- TDS mean values of 36 948 mg/litre and 37 108 mg/litre were measured for the influent and effluent streams respectively (159 mg/litre or 0.4% increase).
- Salinity mean values were 34 785 mg/litre and 34 958 mg/litre (173 mg/litre or 0.5% increase) for the influent and effluent streams respectively.
- Mean dissolved oxygen decreased from 8.10 mg/litre to 7.48 mg/litre (0.61 mg/litre O_2 or 7.46% decrease), and ranged between 5.79 and 9.65 mg/litre.
- A decrease in the mean pH from 8.17 to 8.01 (0.16 or 1.96%) from the influent to the effluent stream was observed while pH ranged between 7.57 and 8.55.
- A 52% (from 1.06 to 0.51 NTU) decrease in the mean turbidity values from the influent to the effluent streams was observed. More importantly, although on occasion the influent turbidity reached values as high as 8.75 NTU the highest effluent turbidity measured, was only 2.34 NTU.

By characterising the combined influent, effluent and effluent$_{200µm}$ sea water streams on a typical South African abalone farm from 21 March up to 9 July 2012 the following could be verified:

- The temperatures of the streams leading up to the SWRO desalination pilot plant (influent, effluent, effluent$_{200µm}$) ranged between a high of approximately 20°C in the summer month of March; a low of approximately 10°C in the autumn month of April. It then stabilised at about 15°C during the winter months of June and July. Mean temperature values of 15.2°C, 15.1°C and 15.6°C were observed for the influent effluent and effluent$_{200µm}$ streams respectively.

- Specific conductance remained relatively unchanged between the inlet, effluent and effluent$_{200\mu m}$ streams, all with a mean value of approximately 53 460 µS/cm, and it ranged largely between 52 000 – 54 000 µS/cm.
- TDS for the inlet, effluent, effluent$_{200\mu m}$ streams varies in the range of 36 000 and 38 000 mg/litre, all with mean values of approximately 37 420 mg/litre.
- Salinity of the influent, effluent and effluent$_{200\mu m}$ streams varied in the range of 34 000 – 36 000 mg/litre, all with mean values of approximately 35 300 mg/litre.
- Mean dissolved oxygen levels of 8.3 mg/ litre, 7.6 mg/ litre and 7.3 mg/ litre were observed for the influent, effluent and effluent$_{200\mu m}$ streams and ranged from 6.5 to 9.8 mg/litre.
- Mean pH values of 8.12, 7.94 and 7.93 were observed for the influent, effluent and effluent$_{200\mu m}$ streams and ranged from 7.71 to 8.37.
- Turbidity of the influent, effluent and effluent$_{200\mu m}$ streams varied in the ranges of 0.22 – 2.17 NTU, 0.28 – 0.82 NTU, and 0.33 – 0.97 NTU respectively; mean values of 0.82, 0.47 and 0.55 were observed for these streams. High turbidity peaks of the influent appeared unconventionally during unforeseen events. The effluent turbidity however always remained NTU < 1.0 which was a good indication for SWRO desalination pre-treatment. Furthermore a gradual increase in turbidity was observed as the influent water quality decreased with the seasonal change from summer to winter.
- The influent $MFI_{0.45}$ had a mean value of 29 s/litre^2 (ranging from 13 to 96 s/litre^2) whereas the effluent $MFI_{0.45}$ had a mean value of 48 s/litre^2 (ranging from 14 to 161 s/litre^2). These amounted to a 66% increase in the $MFI_{0.45}$ from the influent to the effluent. This was not in accordance with the decrease in turbidity.
- The DOC of both the influent and effluent streams was below 1 mg/litre for the duration of the study.

By characterising the UF feed, UF permeate, RO feed, RO concentrate and RO permeate of the SWRO desalination pilot plant stream on a typical South African abalone farm from 21 March to 9 July 2012 the following could be verified:

- The mean temperatures (ranges shown in brackets) of the UF feed, UF permeate, RO feed, RO concentrate and RO permeate streams were 15.5°C (11.3 – 21.5°C), 16.0°C (11.8 – 22.1°C), 16.4°C (12.4 – 22.2°C), 23.9°C (19.1 – 29.1°C), and 25.3°C (20.3 – 29.8°C) respectively.
- Mean specific conductance for the UF feed, UF permeate, RO feed, RO concentrate and RO permeate streams were 53 4440 µS/cm (50 058 – 54 127 µS/cm), 53 434 µS/cm (52 671 – 53 742 µS/cm), 53 377 µS/cm (52 151 – 53 744 µS/cm),

1 629 µS/cm (1 383 – 2 122 µS/cm), and 86 337 µS/cm (80 158 – 95 819 µS/cm) respectively.

- The mean TDS values measured for the UF feed, UF permeate, RO feed, RO concentrate and RO permeate streams were 37 421 mg/litre (36 932 – 37 611 mg/litre), 37 331 mg/litre (33 096 – 37 618 mg/litre), 37 176 mg/litre (32 151 – 37 618 mg/litre), 897 mg/litre (759 – 1 166 mg/litre), and 64 755 mg/litre (60 150 – 71 850 mg/litre) respectively. That amounts to a decrease of 97% in TDS from the UF feed to the RO permeate.
- Salinity measured for the UF feed, UF permeate, RO feed, RO concentrate and RO permeate is 35 390 mg/litre (32 840 – 35 790 mg/litre), 35 300 mg/litre (34 720 – 35 540 mg/litre), 35 260 mg/litre (34 360 – 35 540 mg/litre), 820 mg/litre (690 – 1 080 mg/litre), and 61 080 mg/litre (55 960 – 69 030 mg/litre) respectively.
- The mean dissolved oxygen of the UF feed, UF permeate, RO feed, RO concentrate and RO permeate streams is 7.7 mg/litre (6.8 – 9.1 mg/litre), 7.4 mg/litre (5.4 – 8.7 mg/litre), 8.1 mg/litre (5.8 – 9.7), and 5.5 mg/L (5.1 – 6.4 mg/litre) respectively.
- Mean pH values of the UF feed, UF permeate, RO feed, RO concentrate and RO permeate streams are 7.95 (7.41 – 8.30), 7.57 (6.22 – 8.04), 7.51 (5.47 – 8.09), 6.76 (5.40 – 7.87), 7.47 (6.10 – 7.92).
- Turbidity for the UF permeate and RO permeate range between 0.05 – 0.17 NTU and 0.04 – 0.09 NTU respectively with mean values of 0.08 NTU and 0.06 NTU respectively.
- The DOC of all streams were below 1mg/L throughout the study.
- The CSIR laboratory analyses for the feed (UF permeate) and permeate streams of the RO pilot unit confirmed that a very high quality permeate can be produced with RO treatment utilising UF pre-treatment. In the samples analysed the TDS of the RO feed was reduced from 33493 mg/litre to 969 mg/litre (97.1% removal). The metal compounds are also significantly reduced while ammonia was only reduced by approximately 6.5%.

These parameters indicated that the SWRO pilot plant was able to perform well in respect to permeate quality and established the change in water quality as it flowed through the plant. Points of note from the SWRO desalination pilot study utilising UF pre-treatment, carried out from 21 March to 9 July 2012, are as follows:

- Compaction of both the UF and RO membranes contributed to significant initial flux losses – as much as 18% for the PESM UF membranes and 20% for the TFC Polyamide RO membrane. This is in accordance with values indicated in literature.

- Regular CEB of the UF membrane was fundamental for its stable operation. The CEB frequency was not optimised, but a 24 hour CEB cycle period seemed adequate.
- Element A of the UF system performed in a stable manner at an average flux 66 LMH and a recovery of 78% with an average TMP of 0.36 bar. Direct coagulation at 3 mg/litre (as Fe^{3+}) is applied. Water quality was as follows: NTU ~ 0.65, DOC <1 mg/litre.
- Element A of the UF system performed in a stable manner at an average flux of 54 LMH and a recovery of 67% at an average TMP of 0.59 bar without coagulation. Water quality was as follows: NTU ~ 1, DOC <1 mg/litre, $MFI_{0.45}$ ~ 58 s/litre^2.
- Element B of the UF system performed in a stable manner at an average specific flux of 45 LMH and a recovery of 70% with an average TMP of 0.76 bar without coagulation. Water quality was as follows: NTU ~ 0.6, $MFI_{0.45}$ ~ 49 s/litre^2 and DOC <1 mg/litre.
- Element B of the UF system performed in a stable manner at an average specific flux of 41LMH and a recovery of 68% at an average TMP of 0.11bar. Coagulant was dosed at 3 mg/litre (as Fe^{3+}) hydrolysed by means of an in-line venturi with flocculation occurring in a short pipe flocculator. Water quality was as follows: NTU ~ 0.52, $MFI_{0.45}$ ~ 34 s/litre^2 and DOC <1 mg/litre.
- After initial stabilisation and data capturing difficulties the RO membrane was able to perform very well in respect to permeate quality as indicated by the water characterisation studies (~ 97% TDS reduction). A stable normalised (28°C, 56 bar) flux rate of 8 LMH was achieved and membrane integrity remained intact with a salt rejection that ranges from 98.0 to 98.5%. No sudden reduction in permeate flux was observed because of fouling by any unknown constituent present in the UF permeate water.
- DBNPA weekly at a concentration of 10 – 30 mg/litre for 30 minutes seemed to be able to prevent biofouling and CIP was required every 6 to 8 weeks. Scaling could be controlled by means of an antiscalant dosed at 20 mg/litre in the concentrate stream.

CHAPTER 6

6. PLANT INTEGRATION AND COST CONSIDERATIONS

If we could ever competitively, at a cheap rate, get fresh water from salt water, that it would be in the long-range interests of humanity, it would really dwarf any other scientific accomplishments."
-JOHN F. KENNEDY, 1962

The feasibility and viability of integrating an SWRO desalination plant with a typical South African abalone farm cannot be based on the results of the water characterisation and pilot plant studies alone. Therefore this final chapter aims to address the final two aspects of this project, namely; the on-site experience obtained on the South African abalone farm and the SWRO desalination plant cost considerations.

In order to effectively reduce cost it would be beneficial to first determine the origin of desalination costs. Many studies of water desalination cost have been done; cost estimation is however site specific. The variability exists because of the many factors, unique to each plant, influencing desalination costs, the most important being:

- the desalination method,
- feed water salinity,
- feed water quality,
- the energy source,
- the capacity of the plant
- and other site-related factors.

In this chapter, practical concerns, routine processes and abnormal events that have either a positive or negative effect on the operation of an SWRO desalination plant are highlighted. Then typical cost breakdown structures for SWRO desalination are reviewed in order to obtain an estimate of the possible cost savings induced by the integration of an SWRO desalination plant with a typical South African abalone farm.

6.1 ABALONE FARM INTAKE SYSTEM

One of the main benefits of integrating an SWRO desalination plant with a typical South African abalone farm is the shared capital and operational costs of the intake system. With two parties using the intake system there is the benefit of a duel incentive for keeping the intake system running as smoothly as possible. This includes the generators that most South African abalone farms already have, supplying electricity to the pump house in case of power failures. Abalone is very sensitive to water flow rate as well as water 'down-time'. Therefore there is that added assurance that the abalone farm will keep water flow as constant as possible, which in turn is beneficial to the SWRO desalination plant.

6.2 OPERATION AND MAINTENANCE WORKS

The abalone farm management and operation is discussed in detail in the literature review (section 2.3). Scheduled operations that interrupt the flow of water include sump cleaning, 'pigging' of main pipelines and cleaning of the secondary pipelines. Although these are maintenance operations that need to be completed on any SWRO desalination plant, the duration and frequency of these operations probably differs from that on a typical abalone farm. If the SWRO desalination plant is using only a portion of the water flowing through the abalone farm, the interruptions due to these operations may be more than when the desalination plant is operating on its own. The abalone farm with larger water capacity than that of the SWRO desalination plant farm will require more frequent maintenance which interrupts water flow regardless of the amount of the water used by the desalination plant. The duration and frequency differ from one abalone farm to the next. The SWRO desalination plant must make provision for the expected water flow 'down-times' and do maintenance in the water 'down-time' periods. The reduced maintenance cost of the pipelines leading up to an SWRO desalination plant, thanks to the shared costs maintaining the pipelines, is a major benefit. In addition, significant amounts of electrical energy will be saved or at least shared from the operation of intake system pumps by sharing an intake system.

6.3 ABALONE TANK WASH WATER

One of the main concerns is the routine process of washing the abalone tanks. To flush the forty tanks investigated can take up to four days a week, depending on the rate at which labourers clean. This can vary significantly. This means that for four days there may be some tanks somewhere on the farm producing wash water that is blended into the combined effluent stream feeding the SWRO desalination plant. The wash water from the abalone tanks feeding the SWRO plant must therefore be diverted to drain and not to the SWRO feed sump. This approach is already being embraced in new developments by existing abalone

farms in South Africa, although it is done for different reasons. This will ensure a constant flow of high quality feed water to the desalination plant without the need for an excessively large capacity sump.

6.4 ABNORMAL EVENTS

Unforeseen events that occurred during the pilot study and affected water quality, flow rate and 'down-time', included the following: (It is important to note that these events are not limited to the abalone farm and would pose a problem to any intake system)

- **Algal bloom commonly known as red tide.** An algal bloom is a rapid increase in the population of algae in an aquatic system. Algae can multiply quickly in waterways with an overabundance of nitrogen and phosphorus especially in calm and warm weather. Some species can cause harm via the production of toxins or simply because of their accumulated biomass. This phenomenon significantly decreases feed water quality and even causes breakdown or forced shut downs of intake systems. Fouling caused by algae excreted organics can be a major obstacle to the smooth operation of membrane processes (Chiou et al. 2010). The benefit of sharing an intake system with an abalone farm in this case is that the abalone is very sensitive to water quality and more specifically to toxins that can be produced by the algae. The abalone farms are therefore always on the lookout for algal blooms and test them for toxicity as soon as possible. This ensures an early warning to the SWRO desalination plant in order to take the necessary precautions.

- **'Pigging' of one of the main pipelines.** This line was not 'pigged' in 15 years. This event caused some interruptions to the SWRO pilot plant and can also do so for a commercial SWRO desalination plant. However, this is not a common occurrence, but nonetheless it shows that such events do occur and that provision should be made for such interruptions.

- **The occurrence of Pyura stolonifera, commonly known in South Africa as red bait or 'rooi-aas'.** Pyura stolonifera is a sessile ascidian, or sea squirt that lives in coastal water and more specifically on rocky shorelines. They can grow up to 15cm long and get detached from the rocks during very rough sea conditions (Branch 2005). When detached from the rocks, red bait can cause a breakdown or forced shutdown of intake systems – it becomes detached and drifts along with the currents into the water abstraction area of the intake systems. Here they quickly overload the system and start blocking intake meshes, pipelines and pumps causing significant damages and 'down-times' to the intake system. This is not an occurrence that is

caused by the integration of the desalination plant with the abalone farm, but one where the damage and added operational cost are shared.

This concludes the practical concerns, routine processes and abnormal events that have either positive or negative effects on the operation of an SWRO desalination plant. The focus now shifts to the cost considerations of integrating an SWRO Desalination plant with a typical South African abalone farm.

6.5 UNIT PRODUCTION COST OF DESALINATED WATER

The cost of producing fresh water using desalination is influenced by a large number of factors. The annualised cost expenses (ACE) for the production of fresh water per year is based on the sum of the fixed capital cost depreciation rate (FCCDR) per year and the annual operation and maintenance (O&M) cost (Hafez & El-Manharawy 2003) of the entire SWRO desalination process. Once the ACE is set, the unit production cost (UPC) of water (i.e. cost per m^3) is calculated by dividing the ACE by the production rate of the specific plant.

The unit production cost (UPC) is defined as the cost of producing desalinated water per volumetric unit of water produced as shown in equation 6.6.1

$$\boldsymbol{UPC = \frac{ACE\ (FCCDR+O\&M)\ (ZAR/year)}{water\ production\ rate(m^3/year)}} \qquad \textit{equation 6.6.1}$$

The annual or monthly cost of capital or FCCDR (ZAR/year or ZAR/month) can be determined by multiplying the investment cost with the annuity factor, a. The annuity factor is determined from equation 6.6.2.

$$\boldsymbol{a = \frac{i(1+i)^n}{(1+i)^n-1}} \qquad \textit{equation 6.6.2}$$

where

i discount rate (% per year/month)

n the period of full redemption (years/months)

6.6 TYPICAL COST BREAKDOWN STRUCTURES

Cost breakdowns are intensely dependent on the features of the individual plant and it is difficult to develop an accurate model of the breakdown of costs (Wittholz *et al.* 2008). Various authors however have presented typical cost breakdowns for SWRO desalination plants. Table 6.6.1 presents a summary of the capital and operational and maintenance

costs which together form the total cost for building and operating SWRO desalination plants (Kim *et al.* 2009).

Table 6.6.1 *– SWRO desalination project cost breakdown (Kim et al. 2009)*

ITEM	DETAIL
Capital costs	
Construction Costs	*Site Preparation*
	Intake Systems
	Pre-treatment and Post-treatment Systems
	RO System Equipment
	Brine Disposal Systems
	Waste and Solids Handling
	Electrical and Instrumentation Systems
	Auxiliary and Service Equipment Utilities
	Buildings
	Start-up, Commissioning and Acceptance Testing
Project Engineering Services	*Preliminary Engineering*
	Pilot Testing and Detailed Design
	Detailed Design
Project Development	*Administration, Contracting and Management*
	Environmental Permitting
	Legal Services
Project Financing Costs	*Interest During Construction*
	Debt Service Reserve
	Other Financial Costs
Operation and Maintenance Costs	
Fixed O&M Costs	*Power*
	Chemicals
	Replacement of membrane and cartridge filters
	Brine Disposal
Variable O&M Costs	*Labour*
	Maintenance
	Environmental and Performance Monitoring
	Indirect O&M Costs

Semiat (2000) and Poullikkas (2001) demonstrated typical percentage cost breakdown structures for the total production cost of SWRO water. Both authors separate the energy contribution to the water production from the other O&M costs and indicate it as a percentage of the total water production cost. The cost breakdown structures are summarised in Table 6.6.2.

Table 6.6.2 *– Typical SWRO water production cost breakdown structure*

ITEM	SEMIAT (%)	POULIKKAS (%)
Fixed Capital Cost Depreciation Rate (FCCDR)	*37*	*30 – 50*
Operation and Maintenance Costs (O&M)	*19*	*15 – 30*
Electric Energy	*44*	*30 – 50*

From this table it is clear that the cost of capital has a significant effect on the UPC of SWRO water. The cost of capital (and therefore FCCDR) is highly dependent on the interest rate at which the capital is acquired. From these cost structures it is evident that the cost of electrical energy also contributes significantly to the UPC of SWRO water. Wilf and Klinko (2001) demonstrated how sensitive the UPC of SWRO is to features of individual plants. They demonstrated that doubling the cost of electricity for a specific RO process increased the UPC by up to 50%.

Andrianne & Alardin (2003) went further and provided a general trend on the sea water desalination price structure for some capital and O&M items, as illustrated in Table 6.6.3. This trend is based on statistical data available on desalination plants at the time.

Table 6.6.3 *– SWRO desalination plant capital and operating cost breakdown structure adapted from Andrianne & Alardin (2003)*

ITEM	PERCENTAGE (%)
FCCDR	
Intake and outfall structures	*5 – 20*
Pre-treatment including civil works	*5 – 10*
Equipment	*40 – 50*
Membranes	*25 – 35*
Civil works	*5*
O&M	
Electric Energy	*50 – 60*
Maintenance and overhaul	*20 – 26*
Consumables (Chemical & Membrane replacement)	*10*
Personnel costs	*12*

Hafez & El-Manharawy (2003) investigated the economics of SWRO desalination in the Red Sea region, Egypt. They evaluated and discussed the fixed and operating costs of five selected SWRO plants of 250, 500, 2000, 3 500 and 4 800 m^3/day. The feed water TDS ranges between 43 000 – 49 000 mg/litre. The costs associated with these plants were collected from original documents. The data were then normalised to USD in December 2001 and to the investor's property (IP) type contract conditions before comparisons to actual data were drawn. Hafez & El-Manharawy (2003) then demonstrated the operation itemised costs as a percentage of the ACE. From Table 6.6.2 one can assume that the

FCCDR and O&M (including electrical energy) contributes approximately 40% and 60% respectively to the ACE or UPC of water production. The operational itemized costs from this paper are therefore converted to percentages of FCCDR and O&M costs based on this assumption. The results are summarised in Table 6.6.4.

Table 6.6.4 *– SWRO desalination plant operation itemized costs as a percentage of the ACE (Hafez & El-Manharawy 2003)*

ITEM	PERCENTAGE (%)
FCCDR	*(assumed 40% of UPC)*
Intake system	*17.0 – 33.0*
Pre-treatment including civil works	*9.0 – 12.0*
RO desalination Phase	*20.0 – 26.0*
Post-treatment phase	*0.1 – 0.5*
Brine disposal phase	*4.0 – 5.0*
Infrastructure phase	*26.0 – 35.0*
Professional and financing	*5.0 – 7.0*
O&M	*(assumed 60% of UPC)*
Electric Energy	*55.0 – 62.0*
Consumables (Chemicals)	*8.0 – 8.8*
Consumables (Membrane Replacement)	*14.0 – 15.5*
Supervision and Labour	*9.7 – 12.8*

According to Du Plessis *et al.* (2006) the cost of the intake, outfall and post-treatment can contribute between 15% and 30% of the FCCDR costs for a desalination plant.

The main areas expected to yield cost savings in coming years are as follows (Voutchkov 2012):

1. Improvements in Membrane Element Productivity:
    - *Polymeric Membranes (Nano-particles in Polymer Matrix);*
    - *Bio-membranes and Enzymatic Transport of Water*
    - *Carbon Nanotube Membranes*
2. Increased Membrane Useful Life and Reduced Fouling:
    - *Smoother Membrane Surface*
    - *Increased Membrane Material Longevity*
    - *Use of Systems for Continuous RO Membrane Cleaning;*
    - *UF/MF Membrane Pre-treatment*
3. Commercial Forward Osmosis Systems
4. Larger RO Elements, Trains and Equipment.

The focus in the first two areas is on improvements on the RO membranes, which according to the cost breakdown structures contribute 5 – 10% of the O&M costs (3 – 6% of UPC; assuming a 60% O&M contribution to the UPC). Commercial forward osmosis contributes to a reduction mainly in electrical energy, contributing 50 – 62% of the O&M costs (30 – 37% of the UPC; assuming a 60% O&M contribution to the UPC). Larger equipment reduces the unit production cost (UPC) of water due to economies of scale.

This project focuses on the reduction of the capital cost of constructing, operating and maintaining an intake system. In summary, from the available cost breakdown structures discussed in this section, the intake system contributes between 5% and 33% to the FCCDR. The FCCDR typically contributes approximately 40% to the UPC of desalinated water. The intake system will therefore contribute between 2% and 13% to the UPC of desalinated water.

The typical cost breakdown structures discussed in this section can be used to estimate the possible cost savings (R/m^3) that can be achieved by integrating an abalone farm with an SWRO desalination plant. A R/m^3 cost savings estimate is possible, provided that actual plant UPC's for desalinated water is available – the next section covers actual plant cost data.

6.7 ACTUAL PLANT COSTS FROM LITERATURE

A review and assessment of desalination cost literature is offered by Karagiannis and Soldatos (2008). A brief summary of the findings of this paper are given here. Out of the more than hundred cases examined the cost for the desalination of water is divided into the following three categories:

- type of feed water used,
- desalination method
- and the type of energy used.

Although it is not clearly stated in their paper, it is assumed that the values from different sources and currencies are converted to EUR using 2008 December exchange rates. The costs from this paper is therefore converted to the local currency (ZAR) by also using the 2008 December exchange rate (1 EUR = 13 ZAR, 31/12/2008). It is also assumed that in this paper "the cost of water production" refers to the UPC of fresh water and therefore includes the total FCCDR and O&M costs.

Desalination systems can be divided into two categories regarding the type of energy the use. They can either be powered by a conventional source of energy or renewable energy source. The most common source of conventional energy is for example a local energy grid while the majority of desalination plants using renewable energy use wind, solar (photovoltaic) or geothermal sources of energy. Table 6.7.1 presents a summary of the typical water desalination cost in relevance to the type of energy used and the type of feed water desalinated without specifying plant size or the technology applied. Smaller plants typically have a higher UPC for desalinated water than larger plant due to economies of scale. Therefore the high range values can be assumed to be for small plants whilst the low range values would be for larger plants.

Table 6.7.1 *– Cost of desalination with regards to the type of feed water and energy supply reproduced from Karagiannis & Soldatos (2008)*

TYPE OF FEED WATER	TYPE OF ENERGY	COST (€/m^3)	COST (R/m^3)
Brackish	*Conventional*	*0.21 – 1.06*	*2.73 – 13.78*
	Photovoltaic	*4.50 – 10.32*	*58.50 – 134.16*
	Geothermal	*2*	*26*
Sea water	*Conventional*	*0.35 – 2.70*	*4.55 – 35.10*
	Wind	*1.00 – 5.00*	*13.00 – 65.00*
	Photovoltaic	*3.14 – 9.00*	*40.82 – 117.00*
	Solar collectors	*3.50 – 8.00*	*45.50 – 104.00*

The type of feed water for desalination has a significant effect on the cost of water desalination. Table 6.7.2 presents a summary of desalination cost for different size plants with regards to the type of feed water used without specifying the technology used. Typically RO technology will be used for smaller scale plants (1 000 – 5 000 m^3/day) whereas thermal methods are used more often for larger desalination plants (5 000 – 60 000 m^3/day).

Table 6.7.2 *– Cost of water desalination with regards to type of feed water and plant size for all desalination technologies reproduced from Karagiannis & Soldatos (2008)*

TYPE OF FEED WATER	SIZE OF PLANT (m^3/day)	COST (€/m^3)	COST (R/m^3)
Brackish	*< 1 000*	*0.63 – 1.06*	*8.19 – 13.78*
	5000 - 60 000	*0.21 – 0.43*	*2.73 – 5.59*
Sea water	*< 1 000*	*1.78 – 9.00*	*23.27 – 117.00*
	1 000 – 5 000	*0.56 – 3.15*	*23.14 – 40.95*
	12 000 – 60 000	*0.35 – 1.30*	*4.55 – 16.90*
	> 60 000	*0.40 – 0.80*	*5.20 – 10.40*

Desalination methods can be divided in two broad categories: (1) phase change processes or thermal methods and (2) single phase processes (membrane methods). Table 6.7.3 contains a summary of the cost of producing desalinated water for the different thermal methods as well as that for membrane desalination methods for different sized plants. Here the type of feed water is not specified but the lower range values can be ascribed to brackish water desalination whilst the higher range values can be ascribed to sea water desalination.

Table 6.7.3 *– Cost of water desalination with regards to technology used and plant size reproduced from Karagiannis & Soldatos (2008)*

DESALINATION METHOD	SIZE OF PLANT (m^3/day)	COST (€/m^3)	COST (R/m^3)
Multiple-effect distillation	*<100*	*2.00 – 8.00*	*26.00 – 104.00*
	12 000 – 55 000	*0.76 – 1.56*	*9.88 – 20.28*
	>91 000	*0.42 – 0.81*	*5.46 – 10.53*
Multi-stage flash	*23 000 – 528 000*	*0.42 – 1.40*	*5.46 – 18.20*
Vapour compression	*100 – 1 200*	*1.61 – 2.13*	*20.93 – 27.69*
Reverse osmosis (brackish)	*<20*	*4.50 – 10.32*	*58.50 – 134.16*
	20 – 1 200	*0.62 – 1.06*	*8.06 – 13.78*
	40 000 – 46 000	*0.21 – 0.43*	*2.73 – 5.59*
Reverse Osmosis (sea water)	*<100*	*1.20 – 15.00*	*15.60 – 195.00*
	250 – 1000	*1.00 – 3.14*	*13.00 – 40.82*
	1000 – 4800	*0.56 – 1.38*	*7.28 – 17.94*
	15 000 – 60 000	*0.38 – 1.30*	*4.84 – 16.9*
	100 000 – 320 000	*0.36 – 0.53*	*4.68 – 6.89*

In summary then, typical international costs of sea water desalination ranges from €0.40/m^3 to more than €3.00/m^3 (R5.20/m^3 – R39.00/m^3) for conventional systems. Brackish water desalination cost is about half of that. The use of renewable energy sources increases costs significantly and can reach as high as €15.00/m^3 (R195.00/m^3).

By applying the costing guidelines presented in *A Desalination Guide for South African Municipal Engineers* (*Du Plessis et al.* 2006), the UPC of desalinated water for a 4000m^3/day plant on the south coast of South Africa would have been approximately R9.15/m^3 in 2008 (translating to approximately R13.09/m^3 in 2012 when compensating for inflation).

Based on the work by Karagiannis & Soldatos (2008), the desalination of 4000 m^3/day sea water, using conventional energy supply and membrane-based methods would have cost between €0.56/m^3 and €1.38/m^3 (R7.28/m^3 – R17.94/m^3) in 2008.

The study by Lamei *et al.* (2008), not included in the review by Karagiannis & Soldatos (2008), provides the UPC, FCCDR and O&M costs for a number of SWRO desalinations plants in Egypt, the Mediterranean region and Saudi Arabia (all in terms of 2001 USD). The article covers a wide range of plant capacities from 250 to 50 000 m^3/day some of which were commissioned before 2001 and others after. A summary of some of the results from this study are offered in Table 6.8.4, all values have been converted to ZAR from USD using the yearly average exchange rate for 2001 (1 USD = 8.25 ZAR, 2001 average). The UPC of water is determined with an assumed plant output of 90% of capacity for all plants. The annual cost of capital is calculated by multiplying the investment cost with the annuity factor, a (see equation 6.6.2). The annuity factor was calculated using an interest rate of 8%, an economic plant life of 10 years and an RO plant equipment life of 20 years. South Africa's repo rate in July 2012 was 5.0% and the prime rate at the country's retail banks was 8.5%, which is similar to the interest rate used in the study by Lamei *et al.* (2008).

Table 6.7.4 *– RO Desalination costs in Egypt and in the Mediterranean region and Saudi Arabia (Lamei et al. 2008)*

LOCATION	CAPACITY (m^3/day)	UPC (R/m^3)	FCCDR (R/m^3)	FCCDR (% UPC)	O&M (R/m^3)	O&M (% UPC)
Egypt	*250*	*26.48*	*6.11*	*23*	*20.38*	*77*
Egypt	*300*	*15.02*	*7.34*	*49*	*7.67*	*51*
Egypt	*350*	*11.22*	*3.55*	*32*	*7.67*	*68*
Egypt	*500*	*24.26*	*5.94*	*24*	*18.32*	*76*
Egypt	*500*	*11.72*	*4.04*	*35*	*7.67*	*65*
Egypt	*500*	*10.31*	*3.22*	*31*	*7.18*	*70*
Egypt	*2 000*	*18.40*	*4.79*	*26*	*13.61*	*74*
Egypt	*3 500*	*17.16*	*4.79*	*28*	*12.46*	*73*
Egypt	*4 000*	*13.78*	*6.02*	*44*	*7.67*	*56*
Egypt	*4 000*	*16.67*	*6.60*	*40*	*10.15*	*61*
Egypt	*4 800*	*12.79*	*3.71*	*29*	*9.08*	*71*
Egypt	*5 000*	*12.71*	*4.79*	*38*	*8.00*	*63*
Libya	*7 000*	*9.98*	*4.21*	*42*	*5.78*	*58*
Tunis	*10 000*	*9.74*	*3.63*	*37*	*6.11*	*63*
Saudi Arabia	*15 000*	*9.49*	*3.38*	*36*	*6.11*	*64*
Saudi Arabia	*20 000*	*8.58*	*3.14*	*37*	*5.45*	*63*
Saudi Arabia	*30 000*	*7.67*	*2.97*	*39*	*4.70*	*61*
Cyprus	*40 000*	*7.34*	*2.64*	*36*	*4.70*	*64*
Cyprus	*50 000*	*7.10*	*2.48*	*35*	*4.62*	*65*

The results show that for a medium sized desalination plant (with a capacity of 4000 m^3/day) the UPC of desalinated water range between R13.78/m^3 and R16.67/m^3 with the FCCDR contributing between 39.0 and 43.0% and the O&M contributing between 57% and 61.0% to the UPC. These results are in accordance with the typical cost breakdown structures already discussed. The UPC of desalinated water in 2001 is on the high range side of the range provided by Karagiannis and Soldatos (2008) (R7.28/m^3 – R17.94/m^3) in their review paper (see Table 6.7.3 in this dissertation). This can be explained by the decrease in the cost of desalination in recent years to technological advancements.

6.8 SUMMARY

From the various literature sources available and discussed in this chapter it is safe to assume a FCCDR contribution of 40% and an O&M contribution of 60% to the UPC of desalinated water for a plant with 4000 m^3/day capacity at an interest rate of 8.0% as summarised in Table 6.8.1.

Table 6.8.1 *– FCCDR and O&M contributions to the UPC of desalinated water*

% of UPC (R/m^3)	Semiat (2000)	Poulikkas (2001)	Lamei *et al.* (2008)
FCCDR	*37*	*30 – 50*	*39 – 43*
O&M	*19*	*15 – 30*	*57 - 61*
Electric Energy	*44*	*30 – 50*	

Furthermore, also from the available literature discussed in this chapter the intake system will contribute between 5%-33% to the FCCDR part of the UPC of desalinated water as summarised in Table 6.8.2.

Table 6.8.2 *– Intake system contribution to FCCDR*

% of FCCDR	Hafez *et al.* (2003)	Andrianne *et al.* (2003)	Du Plessis et al. (2006)
Intake	*17 – 33*	-	-
Intake and outfall	-	*5 – 20*	-
Intake , outfall and post treatment	-	-	*15 – 30*

The UPC of desalinated water for a plant with 4000 m^3/day capacity will range between R7.28/m^3 and R17.94/m^3 if all the literature sources discussed in this chapter are considered (see Table 6.8.3)

Table 6.8.3 *– FCCDR and O&M contributions to the UPC of desalinated water*

Source	UPC in 2008	Comment
Du Plessis et al. (2006)	*R9.15/m^3*	*Cost model*
Lamei et al. (2008)	*R13.78/m^3– R16.67/m^3*	*Plant Data*
Karagiannis et al. (2008)	*R7.28/m^3– R17.94/m^3*	*Plant Data*

Consequently the possible cost savings (in R/m^3) incurred by integrating an SWRO farm with an abalone farm, within the ranges determined from literature as discussed here are summarised in Table 6.8.4.

Table 6.8.4 *– Possible cost savings incurred by integrating an SWRO desalination plant with a typical South African abalone farm*

UPC (R/m^3)		**INTAKE SYSTEM CONTRIBUTION TO UPC**	
		2%	**13%**
HIGHER LIMIT	**17.94 R/m^3**	*0.36 R/m^3*	*2.37 R/m^3*
LOWER LIMIT	**7.28 R/m^3**	*0.15 R/m^3*	*0.96 R/m^3*

Important to note is that the UPC can still vary significantly depending site-specific factors for each plant. The same applies for the contribution of the intake system to the FCCDR. However Table 6.8.5 gives a good estimate of the possible cost savings incurred by the integration of a desalination plant with an abalone farm. In addition, the financing and sharing of the costs for the intake system will depend on the type of contract agreed upon between the stakeholders involved. Four standard contract types exist in the region of study, namely:

- Investor's property (IP) contract type.
- Operation and Maintenance (O&M) contract type
- Build own operate transfer (BOOT) contract type.
- Build own operate (BOO) contract type.

For more detail on theses contract types the reader is referred to the paper by (Hafez & El-Manharawy 2003).

CHAPTER 7

7. CONCLUSIONS

7.1 WATER CHARACTERISATION: INDIVIDUAL ABALONE TANKS

By characterising the influent and effluent sea water of forty individual abalone tanks on a typical South African abalone farm it was verified that these forty tanks can adequately represent the entire abalone farm. The standard deviations in important water characterisation parameters, between the individual tanks, were small enough to assume that all the tanks on the farm have a similar effect on the sea water flowing through them. A pilot study could therefore be performed on the combined effluent from a sub-set of tanks on the abalone farm.

The individual tanks do not influence temperature, conductivity, TDS, salinity or the pH of the water significantly. The changes observed for the mean values of these parameters between the tanks were very small and not significant if compared to the accuracy of the instrument used to measure these parameters on site.

The dissolved oxygen levels in the water were significantly reduced as it passed through the abalone tanks as the molluscs consumed the oxygen. However, according to literature, the reduction in dissolved oxygen should not influence the desalination process.

Influent water turbidity was reduced significantly by the abalone tanks. A decrease of 52% in the mean turbidity values from 1.06 to 0.51 NTU was observed for individual tanks. More importantly, although on occasion the influent turbidity reached values as high as 8.75 NTU, the highest effluent turbidity was only 2.34 NTU. This also indicated the tanks' ability to significantly reduce large fluctuations in the turbidity of the influent sea water. From these results one could conclude that the effluent water should place a lower load on the pre-treatment for reverse osmosis than the influent water would, reducing its required intensity and/or capacity. However, $MFI_{0.45}$ tests, performed later on the combined feed and effluent streams, indicated differently – as will be discussed in section 7.2.

7.2 WATER CHARACTERISATION: COMBINED STREAMS

From the characterisation of the combined influent and effluent sea water streams important observations could be made. Laboratory analyses by the CSIR indicated that the composition of the influent was typical of Atlantic seawater. Overall, the abalone tanks did not have any significant effect on the chemical composition of the seawater. One important observation was that the DOC – an indicator of organic matter – of both the influent and effluent streams were always below 1 mg/litre. Consequently it could be interpreted that flocculation may not be required as part of pre-treatment for RO. The overall descriptive statistics for turbidity showed that the mean turbidity of the combined influent was decreased by almost 43% (from 0.82 to 0.47 NTU) as it flowed through the various abalone tanks to become the combined effluent stream. Even with high peaks in influent turbidity the effluent turbidity from the tanks were always <1.0 NTU, again suggesting a low load on pre-treatment for RO.

However, it was found that the UF pre-treatment unit of the SWRO desalination pilot plant operated better with pre-flocculation than without it although the low turbidity and DOC levels suggested that flocculation may not be required. One explanation for this is that there were foulants present in the effluent that could not be detected by DOC analyses or turbidity measurements. The $MFI_{0.45}$ tests highlighted the inability of turbidity alone to predict the fouling potential of feed water to SWRO desalination plants. The influent $MFI_{0.45}$ had a mean value of 29 s/litre^2 (ranging from 13 to 96 s/litre^2) whereas the effluent $MFI_{0.45}$ had a mean value of 48 s/litre^2 (ranging from 14 to161 s/litre^2). These translated to a 66% increase in the $MFI_{0.45}$ from the influent to the effluent (while the turbidity showed a 43% decrease from influent to effluent). The foulants that caused the increased $MFI_{0.45}$ values in the effluent stream were therefore too small to be detected by turbidity readings. The $MFI_{0.45}$ is linear with regards to foulant concentration and gives a more accurate indication of the filterability of the water. Therefore, according to the $MFI_{0.45}$ results, the effluent would pose a slightly higher fouling potential on UF membranes than the influent water.

7.3 PILOT STUDY

Membrane compaction (as also confirmed in literature) was found to play a significant role in initial flux losses for both the UF and RO membranes. Flux losses of as much as 18% for the PESM UF membranes and 20% for the TFC Polyamide RO membrane could be attributed to this phenomenon.

The UF pre-treatment unit operated better with flocculation and provision should therefore be made for flocculation when pre-treating abalone farm effluent water even if the turbidity and DOC levels of the effluent are low (DOC <1 mg/litre, NTU <1). The UF was able to operate

at a specific fluxes ranging between 45 and 55 LMH at a recovery ranging between 60 and 75% at a TMP between 0.59 and 0.76 bar without flocculation. However, with flocculation (Fe^{3+} at 3 mg/litre) the UF was able to operate at a flux ranging from 40 to 65 LMH, at a recovery ranging between 65 and 70% and a much reduced TMP of between 0.11 and 0.36 bar with in-line coagulation and flocculation.

Regular CEB of the UF membrane was fundamental for its stable operation. Although the CEB frequency was not optimised, a 24 hour CEB cycle period seemed adequate. From the UF unit pilot study results it can be concluded that UF is a sensible pre-treatment method for SWRO desalination of abalone farm effluent water.

After initial stabilisation and data capturing difficulties the RO membrane was able to perform very well in respect to permeate quality as indicated by the water characterisation studies (~97% TDS reduction). A stable normalised (28°C, 56bar) flux rate of 8 LMH was achieved (typical of the last membrane in a full-scale SWRO bank) and membrane integrity remained intact with a salt rejection that ranged from 98.0 to 98.5%. No sudden reduction in permeate flux was observed because of fouling by any unknown constituent present in the UF permeate water. Although the frequency of DBNPA dosing was not optimised, it appears to be possible to control RO microbial fouling by means of weekly DBNPA dosing at a concentration of 10 – 30 mg/litre for 30 minutes. Scaling can be controlled by means of an antiscalant dosed at 11 mg/litre in the feed stream, but this will obviously depend on the specific antiscalant used. A CIP frequency of once every 6 – 8 weeks should be adequate to prevent permanent RO membrane fouling. From the RO unit pilot study results it can be concluded that RO is able to effectively desalinate abalone effluent water.

7.4 PLANT INTEGRATION AND COST CONSIDERATIONS

Integration of an SWRO desalination plant with a South African abalone farm can have the following advantages:

- no lengthy and costly EIA required to build a new intake system
- shared capital and operational cost of intake system
- dual incentive to keep constant good quality water flowing through the farm
- early warnings regarding occurrences such as algal bloom and red bait
- shared operational and management cost to keep pipelines clean
- electricity saved (pumps for intake system)

Integration of an SWRO desalination plant with a South African abalone farm can have the following disadvantages:

- will require splitting of the abalone tank wash water from regular effluent
- possible water ‘down-times ‘ due to maintenance operations on abalone farm
- more expensive bulk water supply systems – abalone farms not always situated at optimum position for integrating the desalination plant with existing water supply infrastructure

The cost to produce desalinated water with a medium sized plant (~ 4 000 m^3/day) using conventional energy supply and membrane based methods is between 0.56 and 1.38 €/m^3 (7.28 – 17.94 R/m^3) in 2008. Furthermore, the FCCDR and O&M cost typically contribute approximately 40% and 60% to the UPC of desalinated water respectively. In addition the SWRO desalination plant intake system contributes between 5% and 33% to the FCCDR. The intake system will therefore contribute between 2% and 13 % to the UPC of desalinated water. A possible cost saving of between 0.15 R/m^3 and 2.37 R/m^3 is therefore implied. However, this cost saving is dependent on the UPC of desalinated water as well as the percentage cost contribution of the intake system to the FCCDR.

Integration of an SWRO desalination plant with a South African abalone farm is feasible and viable, should the necessary steps and precautions be taken to ensure a smooth and stable operation of the SWRO desalination plant. Significant cost savings are therefore possible on the part of all the stakeholders provided that the correct contract can be agreed upon.

CHAPTER 8

8. RECOMMENDATIONS

If an SWRO desalination plant is integrated and co-operated with a South African abalone farm, operational agreements that address communications, flow scheduling, functional constraints, and cost sharing arrangements should be negotiated and agreed to as part of the integration process.

Before an SWRO desalination plant is integrated and co-operated with an abalone farm it is important to determine the site specific additional design and construction requirements. These may include:

- a separate flushing system for the abalone wash water;
- a sump with capacity large enough to supply water during scheduled water flow 'down-times';
- integration of SWRO desalination brine discharge stream with abalone farm outflow (ensure agreement with environmental impact regulations)

It is important to refine and optimise the site specific required dosing rates of coagulant, antiscalant and DBNPA to the UF and RO units respectively. It would also be beneficial to determine the optimal CEB and CIP frequencies to possibly further reduce costs.

The implementation of conventional pre-treatment remains an option. If conventional pre-treatment is considered proper coagulation and flocculation as well as a recycle stream for the maturation of a filter cake on the media filter is recommended.

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APPENDICES

A. ADDITIONAL INFORMATION

A.1 LANGLIERS SATURATION INDEX (LSI) AND STIFF AND DAVIS STABILITY INDEX (S&DSI)

The Langlier Saturation Index is defined as follows:

$$LSI = pH - pH_S$$
$$pH_S = pCa + pAlk + pK_2 - pK_S$$

equation A1.1

where

$pH = pH_S$	$level\ at\ which\ H_2O\ is\ in\ equilibrium\ with\ CaCO_3$
pCa	$-log_{10}[Ca^{2+}(\mathrm{mol/L})]$
$pAlk$	$-log_{10}[Alk(\mathrm{mol/L})]\ (Alk = total\ alkalinity)$
pK_2	$-log_{10}[K_2(\mathrm{mol/L})]\ (K_2 = ionization\ constant\ of\ HCO_3)$
pK_2	$-log_{10}[K_S(\mathrm{mol/L})]\ (K_S = solubility\ product\ of\ calcium\ carbonate)$

The Davis Stability Index is defined as follows:

$$S\&DSI = pH - pH_S$$
$$pH_S = pCa + pAlk + K$$

equation A1.2

where

pK	$-log_{10}[K(\mathrm{mol/L})]\ (K = ionic\ strength\ constant)$

LSI and S&DSI should be smaller than 2-2.5 to reduce acid consumption when controlling $CaCO_3$ scaling by acid addition without additional antiscalants (Fritzmann et al. 2007).

Precipitation of $CaCO_3$ can be prevented by pH adjustment via acid addition. At acidic pH values the equilibrium according to equation A1.4 is shifted to the left increasing the solubility of $CaCO_3$. The pH of RO feed is therefore typically maintained between values of 4-6 (Fritzmann et al. 2007).

$$Ca^{2+} + HCO_3^- \leftrightarrow H^+ + CaCO_3$$

equation A1.4

Carbonate, sulphate and calcium fluoride scaling can also be avoided by the addition of antiscalants. Silica complicates RO desalination as threshold limits are difficult to predict as it is affected by a large number of parameters. Silica scaling is difficult and costly to remove – recovery limits are therefore restricted below the saturation limit of silica with antiscalant (220mg/L) or without antiscalant (120mg/L) (Fritzmann et al. 2007).

A.2 SILT DENSITY INDEX (SDI)

A.2.1 SDI equipment

Typical equipment required to measure SDI consists of four basic parts namely a toggle or ball valve, a pressure regulator, a pressure gauge and a filter holder as shown in Figure A2.1

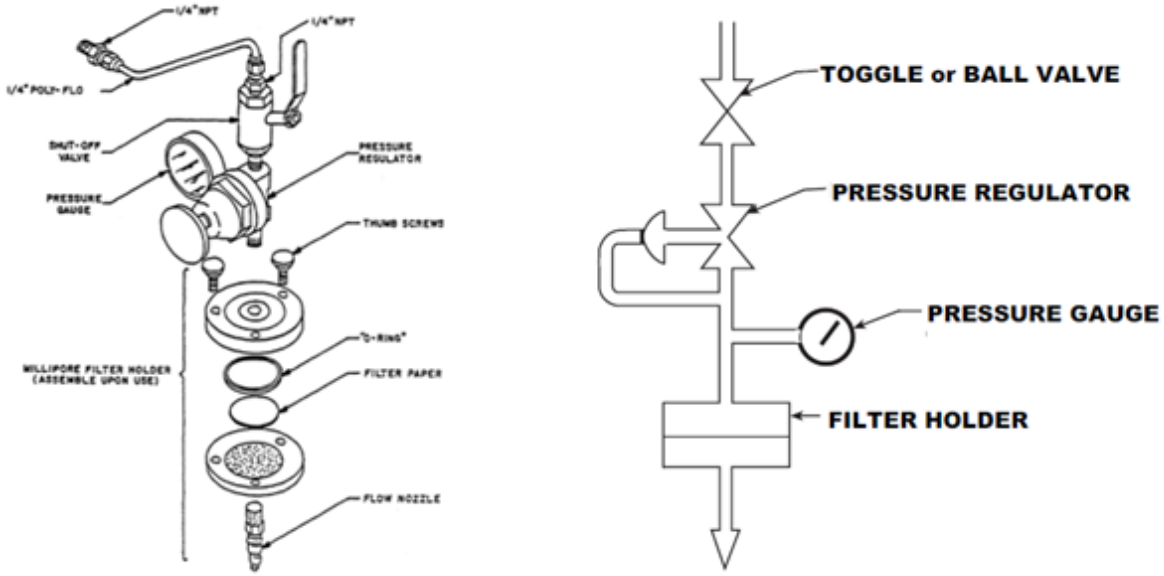


Figure A.2.1 *- Apparatus for measuring the silt density index*

A.2.2 SDI measurement

SDI is determined by the rate of plugging of a membrane filter with pores of 0.45µm at 207kPa. The measurement is done in the following steps:

1. The time t_i is determined which is required to filter the first 500ml
2. Fifteen minutes (T) after the start of this measurement time t_f is measured which is the time is require to filter 500ml
3. The index is then calculated by equation A2.2 shown here:

$$SDI_T = \frac{\%P_{30}}{T} = \frac{\left[1 - \frac{t_i}{t_f}\right] 100}{T}$$

equation A2.2

where

SDI_T	silt density index
$\%P_{30}$	percent at 207kPa (30 psi) feed pressure
T	total elapsed flow time (usually 15 minutes)
t_i	initial time required to collect 500ml of sample
t_f	time required to collect 500 ml of sample after test time T

Important aspects from the ASTM D4189-07 (ASTM 2007) that should be highlighted are the following.

1. The SDI test method is not an absolute measurement of the quantity of particulate matter since the size, shape and nature of particulate matter in water may vary. SDI is therefore a parameter that represents the fouling potential of water on a membrane and not only the quantity of particulate matter in water.

2. It is also important to note that there are hydraulic differences between the analysis method and real RO plant conditions. RO membranes are operated in cross flow configuration while the SDI test is uses dead-end filtration. Furthermore biological growth and fouling will not show within fifteen minutes although it can significantly foul real RO membranes over longer periods of time. Behaviour on a RO membrane can therefore differ drastically from that of the test.

3. The SDI measurement is highly dependent on the type of membrane used. The ASTM D4189-07 (ASTM 2007) document therefore specifies the type of membrane to be used:
    - Membrane – white hydrophilic, mixed cellulose nitrate (50-75%) and cellulose acetate (MCE).
    - Mean Pore Size – 0.45µm.
    - Diameter – 47mm nominal, plain.
    - Thickness – 115-180µm
    - Pure Water Flow Time – 25-50 seconds/500ml
    - Pressure – 91.4-94.7kPa
    - Bubble Point – 179-248kPa
    - Orientation – use only filters packaged in same orientation

A.2.2 SDI Sensitivity

The guidelines for RO operation using the SDI test as reference are as follows (El-Dessouky & Ettouney 2002).

SDI < 1	:	High quality feed water that would provide trouble free operation for years.
1 < SDI <3	:	Moderate to low quality feed water that would allow for a few months of operation before requiring membrane cleaning.
3 < SDI < 5	:	Low quality feed water requiring frequent membrane cleaning.
SDI > 5	:	Very poor water quality - operation at these conditions are unacceptable.

These are general guidelines which are not always reliable and should not be used as the only criteria for determining pre-treatment effectiveness. Different RO manufacturers use different limits for the feed water SDI, depending on their experiences and the RO membrane instructions (Koch Membranes 2011; DOW 2012; TOYOBO 2011; Hydranautics 2011) :

- Toyobo recommend a maximum SDI of 4 for all their RO products (HR, HM, HB, HJ, HL series);
- DOW recommend a maximum SDI of 5 for their RO Filmtec^{TM} Membranes
- Hydranuatics recommend a maximum SDI of 5 for most of their RO products (ESPA, LFC, ESNA1LF, SWC and CPA) with the exception of a maximum recommended SDI of 4 for ESNA1LF2
- Koch recommended a maximum SDI of 5 for all their RO products (TFC: SS, HF, HR, XR, ULP and ROGA HR)

SDI measurements are sensitive and there are some difficulties to ensure good analytical precision for the raw water.

A pre-treatment method such as UF has to guarantee a fine hollow fibre feed water with an SDI < 3. An SDI test is one of the criteria in designing new desalination plants and has to be performed on the RO feed water. The SDI is a useful tool to monitor the efficiency of the RO pre-treatment in removing the particles present in the raw water (Alhadidi et al. 2011).

Repeatability is often subject to controversy particularly due to operator's technique difference as well as the type of membrane used. The main precautions to be followed prior

to SDI testing are: (1) Equipment flushing, (2) air purge, (3) membrane wetting, (4) avoid direct contact of membrane with hands (Mosset et al. 2008).

In the study by *Mossett et al.* (Mosset et al. 2008), SDI was found not to be sensitive to a change in pressure when that specific pressure is maintained constant throughout the test (percent plugging varied between 35% and 38% between pressures of 2.00 to 2.20 bars). However if pressure varies during the test higher SDI values will be observed. Some elements that could cause severe RO membrane fouling are not detected by this test such as dissolved iron from coagulation pre-treatments.

A.2.3 SDI and Turbidity

Fresh water turbidity and SDI have been shown to correlate (Mosset et al. 2008), however this may not always be the case and turbidity increase is not always associated with SDI increase. SDI values themselves will not always render significant information on detecting potential risks of particulate fouling of RO membranes. For monitoring purposes of RO feed with MF/UF pre-treated water a high sensitivity turbidity meter recording down to 0.001NTU is recommended (Alhadidi et al. 2011):

A.2.4 Factors Affecting SDI measurement

The effects of temperature, Cl_2 and pH on SDI measurements are as follows (Ando *et al.* n.d.):

temperature – *Higher UF pre-treated water temperature results in higher SDI values*

Cl_2 – *Higher Cl_2 concentrations lead to higher SDI values. SMBS dosing decreases SDI due to resolving plugging colloidal substances.*

pH – *Higher UF pre-treated water pH, the higher the SDI values. This is due to the proneness of $CaCO_3$ to precipitate on the alkaline side.*

membrane – *As stated in the ASTM 4189-07 document the type of membrane used is determinant for SDI values.*

In research by Ando *et al.* (Ando et al. n.d.) SDI measurements with hydrophilic and hydrophobic membranes are compared and the results are summarised here in Table A2.4. It is evident that the hydrophilic membranes give better SDI values than hydrophobic membranes and that wettability is a very important factor that must be considered. The latest ASTM D4189-07 (ASTM 2007) document specifies the type of filter to be used.

Table A2.4 *– Comparison of SDI data using different 0.45µm pore size hydrophobic and hydrophilic MF filters with typical UF filtrate (Ando et al. n.d.).*

Filter Code	Material	Wettability	SDI values with different filters		Standard SDI values (HAWP filter)	
			SDI_{15min} Value	$T_{(0)}/T_{(15)}$ (s)	SDI_{15min} Value	$T_{(0)}/T_{(15)}$ (s)
HAWP	MCE	hydrophilic	3.22	20.30/39.32	3.08	19.30/35.90
HVLP	PVDF	hydrophilic	1.23	22.33/27.37	3.27	17.95/35.28
HVHP		hydrophobic	3.38	31.65/64.15	3.28	18.45/36.28
JHWP	PTFE	hydrophobic	4.38	30.69/89.36	3.41	18.15/37.24
250006-47-N	PA	hydrophilic	1.21	55.49/67.97	3.23	18.33/35.60

A.3 ORGANIC MATTER MEASUREMENT

There are a number of routine and novel organic matter measurements and characterisation protocols that can be applied to characterise bulk samples of feed water, the most important ones are as follows:

1. Dissolved organic carbon (DOC). DOC represents the amount of OM.
2. Dissolved organic nitrogen. DON embodies the nitrogen content of OM.
3. Ultraviolet absorbance at 254nm (UVA_{254}). UVA_{254} reflects the aromatic character of OM. UVA_{254} absorbance is sensitive to aromatic components and is an indicator for both humic and fulvic acid presence (Zularisam et al. 2006; Gary 2008)
4. Specific ultraviolet absorbance at 254nm. SUVA is a ratio of UVA_{254} and DOC (SUVA = UVA_{254}/DOC). SUVA reveals the relative amounts of humic OM (higher SUVA) vs. non-humic OM (lower SUVA). A higher SUVA means high aromaticity or hydrophobicity of samples in low DOC (Zularisam et al. 2006; Gary 2008).
5. Molecular weight (MW) distribution by high pressure size exclusion chromatography with on-line UV and DOC detection (SEC-DOC) which is conceptually equivalent to liquid chromatography with organic carbon detection (LC-OCD). This describes the OM in terms of chromatographic peaks corresponding to; (1) high molecular (MW) polysaccharides; (2) medium MW humic substances (humin, humic acid and fulvic acid), and (3) low MW acids (Zularisam et al. 2006; Gary 2008).
6. Hydrophobic/transphilic/hydrophilic DOC distribution by XAD-4/XAD-8 resin adsorption chromatography. The most common technique for isolation of NOM fractions are gel filtration, UF and adsorption using non-ionic and macro porous ion-exchange resins XAD-4/XAD-8. Water is fractionated in hydrophobic (adsorbed by XAD-8), transphilic (adsorbed by XAD-4) and hydrophilic components (passes through both XAD-4 and XAD-8 resins) .This reveals a polarity distribution of OM (Zularisam et al. 2006; Gary 2008).

7. Fluorescence excitation-emission matrix (EEM) in the form of 3-dimensional spectra. This distinguishes between humic-like and protein like OM as well as providing a fluorescence index that is related to OM source (that is terrestrial or microbial)
8. Pyrolysis gas chromatography/mass spectrometry (P-GC/MS). This method describes OM biopolymer composition in terms of polyhydroxyaromatics, polysaccharides, proteins, and amino sugars.

A.4 CHEMICAL PRE-TREATMENT

Chemical pre-treatment includes the addition of any chemicals upstream of the reverse osmosis stage. The type of pre-treatment applied significantly influences the amount of chemicals used, conventional pre-treatment tends to use more chemicals than membrane pre-treatment.

A.4.1 Chlorination/ Biocide (DBNPA)

Chlorine is typically added to water as sodium hypochlorite (NaOCl) or as chlorine gas (Cl_2), which hydrolyses to form hypochlorous acid in the water. The hypochlorous acid then dissociates to form hydrogen and hypochlorite ions (Fritzmann et al. 2007) according to the following reaction A4.1.

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

equation A.4.1.1

$$NaOCl + H_2O \rightarrow HOCl + NaOH$$

equation A.4.1.2

$$HOCl \leftrightarrow H^+ + OCl^-$$

equation A.4.1.3

A.4.2 Coagulation and Flocculation

A.4.2.1 Coagulant Selection

The proper chemicals and dosage is required to maximize the size of the agglomerates formed. Common coagulant chemicals used are alum, ferric sulphate, ferric chloride, ferrous sulphate, and sodium aluminates. The first four will lower the alkalinity and pH of the solution while the sodium aluminates will add alkalinity and raise the pH (Fritzmann *et al.* 2007; Droste 1997).

The choice of coagulant chemical depends upon the nature of the suspended solid to be removed, the raw water conditions, the facility design, and the cost of the amount of chemical necessary to produce the desired result.

Final selection of the coagulant (or coagulants) should be made following thorough jar testing and plant scale evaluation. Considerations must be given to required effluent quality, effect upon downstream treatment process performance, cost, method and cost of sludge handling and disposal, and net overall cost at the dose required for effective treatment.

A.4.2.2 Inorganic Coagulants

Inorganic coagulants such as aluminium and iron salts are the most commonly used. When added to the water, they furnish highly charged ions to neutralize the suspended particles. The inorganic hydroxides formed produce short polymer chains which enhance microfloc formation.

Inorganic coagulants usually offer the lowest price per pound, are widely available, and, when properly applied, are quite effective in removing most suspended solids. They are also capable of removing a portion of the organic precursors which may combine with chlorine to form disinfection by-products. They produce large volumes of floc which can entrap bacteria as they settle. However, they may alter the pH of the water since they consume alkalinity. When applied in a lime soda ash softening process, alum and iron salts generate demand for lime and soda ash. They require corrosion-resistant storage and feed equipment. The large volumes of settled floc must be disposed of in an environmentally acceptable manner.

The most commonly used inorganic coagulants and their reactions are as follows (Fritzmann et al. 2007).

A.4.2.2.1 Iron

A.4.2.2.1.1 Ferric Sulphate

$$Fe_2(SO_4)_3 + 3\,Ca(HCO_3)_2 \rightarrow 2\,Fe(OH)_3 + 3CaSO_4 + 6\,CO_2$$

A.4.2.2.1.2 Ferric Chloride

$$2\,FeCl_3 + 3\,Ca(HCO_3)_2 \rightarrow 2\,Fe(OH)_3 + 3CaCl_2 + 6CO_2$$

The coagulant most frequently used for desalination plant is iron (III) chloride ($FeCl_3$). This is also the coagulant used throughout this project and it will therefore be worthwhile to look into the coagulation mechanism of iron. With a solubility product of K_{SP} = 27.9 $mol^4 \cdot l^{-4}$, iron chloride is easily dissolved in water. Consequently, 162 mg $FeCl^3$ can be dissolved in one litre of water, resulting in 55.8 mg/l Fe^{3+} and 106.5 mg/l Cl^- (Droste 1997)

In addition to other ions, the ions Cl^-, SO_4^{2-}, Na^+, Ca^{2+}, H_3O^+ and OH^- are dissolved in water. The OH^- ions play an important role in coagulation. Fe^{3+} and OH^- ions precipitate, because the solubility product of iron hydroxide is low. Since K_{SP} ($Fe(OH)_3$) = $1 \cdot 10^{-38}$ $mol^4 \cdot l^{-4}$, only $7.8 \cdot 10^{-10}$ mol/l Fe^{3+} and $2.34 \cdot 10^{-9}$ mol/l OH^--ions can be present in water (Droste 1997).

When the concentration of these ions are higher, they will precipitate into $Fe(OH)_3$-flocs. When the pH of the surface water is known, the concentration of iron ions (Fe^{3+}) can be calculated using the solubility product of iron hydroxide and the ion product of water (Droste 1997):

$$Fe^{3+} + 3 \cdot OH^- \rightarrow Fe(OH)_3 \; K_{SP} = 1 \cdot 10^{-38}$$
$$2 \cdot H_2O \leftrightharpoons H_3O^+ + OH^- \quad K_W = 1 \cdot 10^{-14}$$

Rewriting the water equilibrium results in the following equation:

$$K_W = 1 \cdot 10^{-14} = [H_3O^+] \cdot [OH^-] \Longrightarrow \cdot [OH^-] = \frac{1 \cdot 10^{-14}}{[H_3O^+]}$$

Combining the equation mentioned above with the solubility product of iron hydroxide gives:

$$[Fe^{3+}] + [OH^-]_3 = 1 \cdot 10^{-38}$$
$$[Fe^{3+}] = 1 \cdot 10^{-38} \frac{[H_3O^+]^3}{(1 \cdot 10^{-14})^3} = 1 \cdot 10^4 \cdot [H_3O^+]^3$$
$$log[Fe^{3+}] = 1 \cdot 10^{-38} \frac{[H_3O^+]^3}{(1 \cdot 10^{-14})^3} = log(1 \cdot 10^4) + 3 \cdot log[H_3O^+] = 4 - 3 \cdot pH$$

In addition to iron hydroxide the following hydrolyses products of Fe^{3+} are also formed:

$Fe(OH)^{2+}$, $Fe(OH)^{2+}$, $Fe(OH)^{4-}$.

When the pH of water is known, the amount of hydrolysis product in a volume of water can be determined. With a pH of 4.6, 10^{-7} mol/m3 Fe^{3+}, 10^{-4} mol/m^3 $FeOH^{2+}$ and 10^{-4} mol/m^3 $FeOH^{2+}$ are present.

The pH and the predominant hydrolysis product influence the predominant coagulation mechanisms. As a result of the dosing of iron chloride, OH^- ions are removed and the pH will decrease. The magnitude of the pH drop depends on the buffering capacity of the water. The higher the buffering capacity, the smaller the pH drop is. When the pH drop is too large, pH

will be increased by dosing a base, such as caustic soda. Table A4.2.2.1 summarises the iron hydrolyses reactions.

Table A4.2.2.1 *– Iron hydrolyses reactions (Droste 1997)*

Iron hydrolyses reactions			K_S
$Fe(OH)_3$	←→	$Fe^{3+} + 3OH^-$	$1 \cdot 10^{-38}$
$Fe^{3+} + 2H_2O$	←→	$Fe(OH)_2+ + H_3O^+$	$6.8 \cdot 10^{-3}$
$Fe(OH)_2+ + H_3O+$	←→	$Fe(OH)_2+ + H_3O^+$	$2.6 \cdot 10^{-5}$
$2Fe^{3+} + 4H_2O$	←→	$Fe_2(OH)_2^{4+} + 2H_3O^+$	$1.4 \cdot 10^{-3}$
$Fe(OH)_3 + OH-$	←→	$Fe(OH)^{4-}$	$1.0 \cdot 10^{-5}$

A.4.2.2.2 Ferrous Sulphate

$$FeSO_4 + Ca(HCO_3)_2 \rightarrow Fe(OH)_2 + CaSO_4 + 2CO_2$$

A.4.2.2.3 Alum

$$Al_2(SO_4)_3 + 3\,Ca(HCO_3)_2 \rightarrow 2\,Al(OH)_3 + 3CaSO_4 + 6\,CO_2$$

A.4.2.2.4 Sodium Aluminates

$$2\,Na_2Al_2O_4 + Ca(HCO_3)_2 \rightarrow 8\,Al(OH)_3 + 3\,Na_2CO_3 + 6\,H_2O$$
$$Na_2Al_2O_4 + CO_2 \rightarrow 2\,Al(OH)_3 + NaCO_3$$
$$Na_2Al_2O_4 + MgCO_3 \rightarrow MgAl_2O_4 + Na_2CO_3$$

A.4.2.3 Polymers

Polymers are long-chained, high-molecular-weight, organic chemicals and are becoming more widely used, especially as coagulant aids together with the regular inorganic coagulants. Anionic (negatively charged) polymers are often used with metal coagulants. Low-to-medium weight positively charged (cationic) polymers may be used alone or in combination with the aluminium and iron type coagulants to attract the suspended solids and neutralize their surface charge. The manufacturer can produce a wide range of products that meet a variety of source-water conditions by controlling the amount and type of charge and relative molecular weight of the polymer.

Polymers are effective over a wider pH range than inorganic coagulants. They can be applied at lower doses, and they do not consume alkalinity. They produce smaller volumes of more concentrated, rapidly settling floc. The floc formed from use of a properly selected polymer will be more resistant to shear, resulting in less carryover and a cleaner effluent.
Polymers are generally several times more expensive in their price per mass than inorganic coagulants. Selection of the proper polymer for the application requires considerable jar testing under simulated plant conditions, followed by pilot or plant-scale trials. All polymers must be approved for potable water use by regulatory agencies.

A.4.2.4 Coagulation Mechanisms

Several coagulation mechanisms exist and are discussed here.

A4.2.4.1 Electrostatic coagulation

Electrostatic coagulation occurs in when trivalent ions are dosed at 0.025 mol/m^3 or higher – positive ions then approach the negative colloids accumulating in the diffusive layer around the colloid. The colloid is destabilised though this process, making it possible for the colloids to collide and form flocs.

A4.2.4.2 Adsorptive Coagulation

Adsorptive coagulation occurs when particles or colloids are adsorbed to the positively charged hydrolyses products $FeOH^{2+}$ and $FeOH_2^{+}$. These hydrolyses products are mainly present at low pH – the optimum pH for this coagulation mechanism is therefore between 6 and 8 for iron salt and around 7 for aluminium salts for which the range id narrower.

In adsorptive coagulation the removal of organic matter is proportional to the dosing and that restabilization can occur after an overdose of coagulant. Overdosing will cause the colloids to be positively charged and repulsion of the particles will take place. Adsorptive coagulation is a rapid process and positively charged hydrolyses products are formed and are adsorbed to the negatively charged particles within a second.

A4.2.4.3 Precipitation Coagulation

Precipitation coagulation (also known as sweep coagulation) colloids are incorporated into neutral (iron) hydroxide flocs. This type of coagulation occurs mainly in waters with low suspended solids content (10 mg/litre). Higher dosages of coagulant is necessary than used for adsorptive coagulation in order to form hydroxide flocs.

A.4.2.5 Coagulation in practice

A.4.2.5.1 Jar test

Jar tests are executed to research the coagulation process and to establish the optimum coagulation parameters for a specific water type. A jar test is simply the simulation of the coagulation and floc formation process.

The jar-test apparatus consists of six jars filled with water to each of which a certain dose of coagulant is added. After rapid mixing, a slow stirring, and a settling phase, the water turbidity can be measured to determine the efficiency of the coagulant.

Process conditions (dosage, pH, flocculation time, and settling time, stirring energy for mixing and/or flocculation) are modified to determine the optimal conditions for each specific application.

A.4.2.5.2 Mixing

Rapid mixing after coagulant dosing is an important design parameter. The coagulant must be uniformly mixed with the raw water. In case mixing is poor, local under- and overdosing occurs, resulting in poor performance of the process.

A.4.3 Antiscalants Mechanisms

A.4.3.1 Threshold inhibition

The ability of an antiscalant to keep solutions of sparingly soluble salts supersaturated by adding adsorption and diffusion resistance which, in turn, retards the crystal growth rate (Gloede & Melin 2008).

A.4.3.2 Crystal modification

The ability to distort crystal morphology (crystal shape) leading to selective nucleation. The distortion of crystal shape further leads to the formation of softer non-adherent scales. Negative charges from the antiscalant attack the positive charges on scale nuclei on a microscopic level interrupting the electronic neutrality or balance required for crystal growth (Gloede & Melin 2008).

A.4.3.3 Dispersion

The ability to change the surface properties of the crystal by adsorbing unto the crystals or colloidal particles imparting a high ionic (anionic) charge, keeping the crystal separated and therefore affecting the agglomeration tendency (Gloede & Melin 2008). The choice of the

specific antiscalant depends on the feed water composition. Optimisation of antiscalant type and dose is as important as coagulant optimisation. Higher antiscalant dose does not necessarily decrease salt precipitation (Greenlee et al. 2009).

Depending on the limiting salt, determined via the solubility product, different scale inhibitors are used. They typically control scales formed by sulphates, carbonates, and calcium fluoride. The higher the recovery rate the higher the problem or probability of scaling. Antiscaling is advised for systems working at recoveries higher than 35% and is required independent of the physical pre-treatment applied (Fritzmann et al. 2007).

A.4.4 Dechlorination

The dechorination reactions for SMBS and activated carbon are shown here.

The SMBS reacts with the water to form sodium bisulphite (SBS) according to equation A4.4.1a (Fritzmann et al. 2007):

$$Na_2S_2O + H_2O \rightarrow 2HaHSO_3$$

equation A4.4.1a

The SBS then reduces the hypochlorous acid according to equation A4.4.1b *(Fritzmann et al.* 2007):

$$2HaHSO_3O + 2HOCl \rightarrow H_2SO_4 + 2HCl + Na_2SO_4$$

equation A4.4.1b

In practice 3 mg/litre of SMBS is used per 1 mg/litre of free chlorine for dechlorination instead of the theoretically required 1.34 SMBS per 1 mg/litre chlorine (Fritzmann *et al.* 2007).

Activated carbon can also be applied to effectively remove residual free chlorine according to the following reaction shown by equation A4.4.2 (Fritzmann *et al.* 2007):

$$C + 2Cl_2 + 2H_2O \rightarrow 4HCl + CO_2$$

equation A4.4.2

A.5 MEMBRANE PRE-TREATMENT FOR SWRO DESALINATION

A.5.1 Membrane Removal Effendis and Operating Differential Pressures

The pores' size and required differential pressure for MF,UF,NF and RO membranes differ from one another as illustrated in Figure A.5.

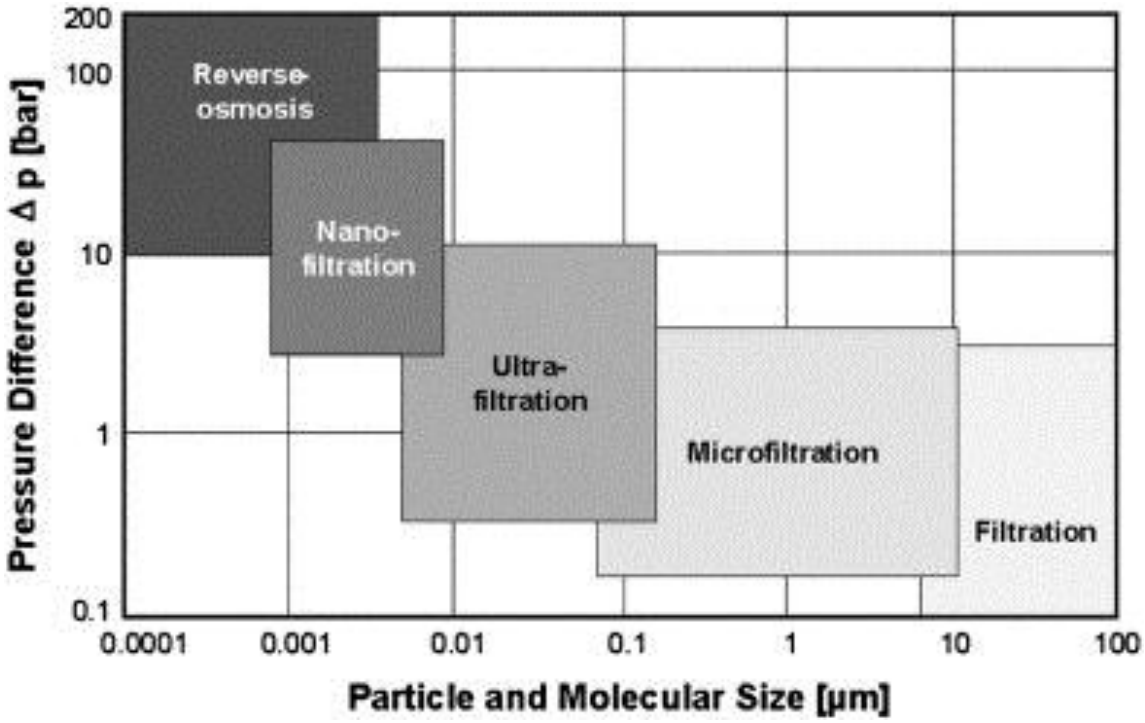


Figure A.5 *– Typical pore size and removal rates for MF, UF, NF and RO membranes (Fritzmann et al. 2007).*

A.5.2 SWRO Membrane Materials

The performance of RO is directly related to the properties of the membrane material and more specifically the chemical nature of the polymer of which the membrane is made as well as the structure of the membrane. The two most common families of RO membranes are cellulose acetate (asymmetric) and polyamide (composite) membranes (Kucera 2010; El-Dessouky & Ettouney 2002).

A.5.2.1 Cellulose Acetate (Asymmetric) Membranes

Cellulose acetate (CA) membranes were the first generation membranes used for desalination. CA membranes are asymmetric (or anisotropic) in that they are made from the same material, but consists of two superimposed layers. CA membranes are typically made of a blend of cellulose diacetate and triacetate (Kucera 2010).

CA membranes are made by dissolving a water soluble polymer (CA) in an organic solvent (for example acetone) and a casting-solution modifier (such as formamide). The solution is then cast into a thin film on a sturdy surface using a thin blade. The film is left for 10 to 100 seconds to allow for the partial evaporation of the solvent which cause an increase in concentration of polymer at the solution/air interface, since the solvent evaporates more rapidly at the surface. This results in two phases forming within this film, (1) a polymer-rich phase and (2) a polymer-poor phase. The membrane is then immersed in water just before the solvent evaporate completely and forms a thin skin (typically 0.1-0.2µm thick) as the remaining polymer diffuses out. Annealing of the membrane is then done at 70° to 90°C forming small voids in the polymer-poor phase creating a porous region (typically 100-300µm thick) which becomes the support structure of the membrane (El-Dessouky & Ettouney 2002; Kucera 2010). The following Table A5.2.1 taken from the book written by *Kucera* [52] summarises the characteristics of cellulose acetate membranes.

Table A5.2.1 *– Characteristics of cellulose acetate RO membranes (Kucera 2010)*

Property	Value for CA membrane
Membrane Type	homogenous asymmetric
Salt rejection (%)	~95
Silica rejection (%)	~85
pH range	2-6
Feed Pressure (brackish membrane)	220-440 psi
Temperature tolerance	up to 30°C
Surface charge	neutral
Chlorine tolerance	up to 1 mg/litre (continuously)
Biological growth	metabolized membrane
Fouling tolerance	good
Surface roughness	smooth

A.5.2.2 Polyamide and Composite Membranes

The low salt rejection and high operating pressure of CA membranes held back the RO technology and in answer to this, polyamide membranes were developed to improve on the performance of CA membranes (Kucera 2010). There are two different types of polyamide membranes:

A.5.2.2.1 Linear Aromatic polyamide membranes

These membranes like CA membranes are created from a single polymer. They exhibit higher rejection and higher flux at a lower operating pressure than CA membranes. The linear aromatic polyamide membranes led to the development of the composite polyamide

membranes which are essentially a composite layer of two polymers cast upon a more structurally sound support layer of usually polysulfone (Kucera 2010).

A.5.2.2.2 Composite polyamide membranes

Composite polyamide membranes or thin film composite (TFC) membranes consists of two layers; (1) a porous polysulfone support layer and (2) a semi-permeable layer of amine carboxylic acid functional groups (typically a composite of two polymers). The most popular RO membranes in use today are cross-linked fully aromatic polyamide membranes (Kucera 2010).

The membranes are formed using interfacial polymerization. A micro porous substrate layer is prepared using the same method as for the cellulose acetate membranes, but without the annealing step so that no skin is formed over the membrane. This substrate is then exposed to monomers with a high water and low salt permeability, such as polyamine. Amine is submersed in a water soluble solvent containing a reactant (such as diacid chloride in hexane) which reacts at the interface of the water and organic solvent forming a highly cross-linked thin film. This thin film layer is typically a semi-permeable polyamide which is 0.04 to 0.1µm thick and the porous layer polysulfone which is 40 to 80µm thick (Kucera 2010; El-Dessouky & Ettouney 2002).

Table A5.2.2.2 taken from the book written by *Kucera* (Kucera 2010) summarises the characteristics of composite polyamide (TFC) membranes.

Table A5.2.2.2 *– Characteristics of polyamide composite (TFC) RO (Kucera 2010)*

Property	Value for PA membrane
Membrane Type	homogenous asymmetric, thin-film composite (TFC)
Salt rejection (%)	~98+
Silica rejection (%)	~96+
pH range	2-12
Feed Pressure (brackish membrane)	145-400 psi
Temperature tolerance	up to 45°C
Surface charge	negative (anionic)
Chlorine tolerance	less than 0.02 mg/litre (continuously)
Biological growth	cause membrane fouling
Fouling tolerance	fair
Surface roughness	rough

A.5.3 SWRO Membrane Modules

Membranes are shaped into specific mechanical forms that can withstand the extremely high operational pressure required for the RO process. The two major membrane module configurations used for RO applications are hollow fibre modules and spiral wound modules. Other less popular configurations include plate and frame membrane modules.

A.5.3.1 Hollow fibre

This configuration uses the membrane in the form of a hollow fibre, extruded from cellulose acetate blend or polyamide type materials. The fibres are asymmetric with an internal diameter of approximately 42µm and an outside diameter of approximately 85µm. Millions of these fibres are then formed into a bundle and folded in half to a length of approximately 1.2m and epoxy sealed at both ends to form a sheet like permeate tube and terminal end preventing the feed stream to bypass the concentrate outlet. A perforated plastic tube, serving as a feed water distributor is inserted in the centre and extends the full length of the bundle.

This hollow fibre bundle (approximately 10 to 20 centimetres in diameter) is contained within a cylindrical pressure vessel (approximately 1.37 metres long and 15 to 30 centimetres in diameter). Pressurized feed water enters the permeator feed through the centre distribution tube, passes through the tub wall flowing in a radial direction around the bundle toward the outer permeator pressure shell. Water flows through the fibre wall into the hollow fibre core to the product end of the fibre bundle. Hollow fibre membranes have the following advantages and disadvantages:

Advantages

- Highest specific area (total area per unit volume) of all module configurations – small footprint.
- Modest energy requirements compared to other configurations.
- Affords controlled hydraulics.
- Tangential flow along membrane surface limits membrane fouling.
- Consistent permeate quality.
- Open process flow channel results in less fouling.
- Membranes can be back flushed to remove solids from membrane surface extending the lifetime of the membranes significantly.
- Modular system design allows for easy future expansion.
- Flexible – can filter by means of two methods: inside-out or outside-in.

- Permeate water flow per unit area of membrane is low, and therefore concentration polarization is low at membrane surface – hollow fibre membranes therefore operate in laminar flow regime.

Disadvantages

- Membrane fouling of hollow fibre is more frequent than other membrane due to its configuration. Contaminated feed will increase the rate of membrane fouling, especially for hollow fibre.
- More expensive than other membranes which are available in market due to its method of fabrication.
- Hollow fibre is a new technology and so far, research done on it is less compare to other types of membrane. More research will be done on it in future however because of its potential.

Figure A5.3.1 shows schematic representations of this configuration.

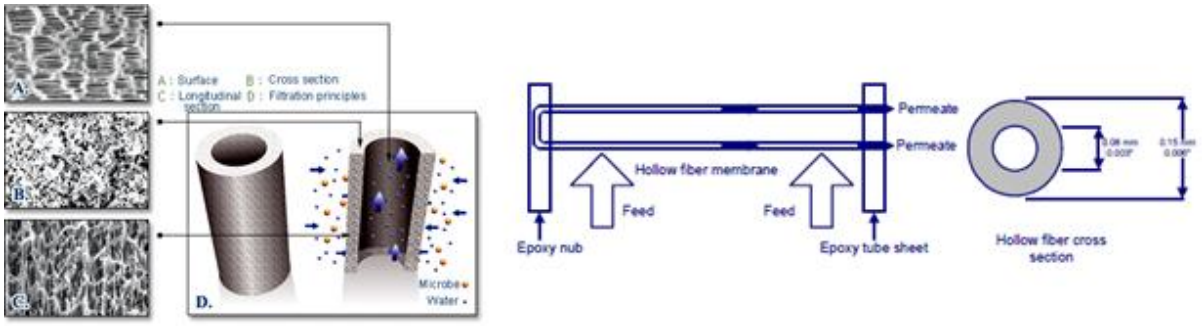


Figure A.5.3.1 *– Hollow fibre configuration (Korea Membrane 2011)*

A.5.3.2 Spiral Wound Membranes

Spiral wound membranes are the current norm and will also be used in this study. In this configuration two membrane flat sheets are separated by a permeate collector material to form a leaf which is sealed on three sides with one side left open for permeate to exit through. A feed/brine spacer material is also added to this leaf assembly. A number of these leaves are wound around a central perforated tube which collects permeate from the multitude of leave assemblies. The flow of water from feed to brine follows a straight axial path from the feed end to the opposite brine end, parallel to the membrane surface. Spiral wound elements are typically manufactured membrane flat sheets of cellulose diacetate and triacetate blends (CA) or a thin film composite. Figure 5.3.2 shows a diagram of a spiral wound module.

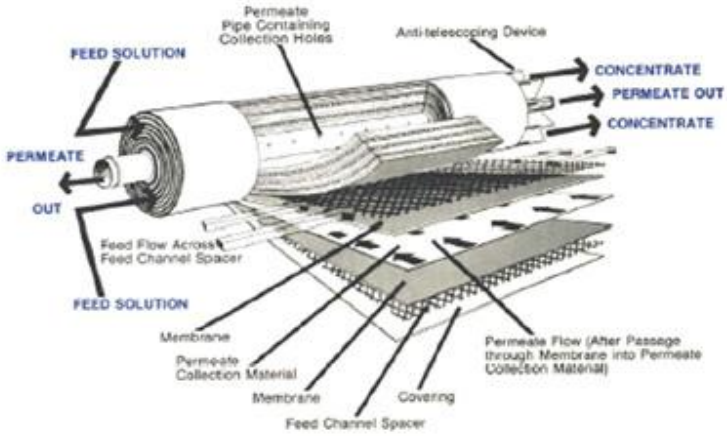


Figure A.5.3.2 *– Spiral wound membrane module (Koch Membranes 2011).*

The advantages and disadvantages of spiral wound modules are as follows:

Advantages

- High packing density
- Elements are easy to replace
- Low pressure drops
- Pressure tolerant
- Lower capital costs
- Lower energy cost to operate

Disadvantages

- Easily clogged by particulates
- Limited ability to control hydraulics within element
- Difficult to clean when heavily fouled
- Intolerant to large pressure differences

B. PHOTOGRAPHS AND P&ID'S

Appendix B contains the photographs from the typical abalone farm and the equipment used in the study. The PFD of a typical South African Abalone farm and the P&IDs of the SWRO Desalination Pilot Plant are also presented.

B.1 ABALONE FARM

Figure B1.1 presents the abalone tanks, on the left is a row of abalone tanks with the wooden walkway over the gulley collecting the effluent water, top right is a photo of the inside of a abalone tank showing the rack and animals inside, bottom right is a photo of the standpipe at the outlet of a tank where the effluent leaves the tank.

Figure B.1.1 *– Abalone tanks*

Figure B.1.2 presents the PFD of a typical South African abalone farm.

F-101 Kelp Filter
F-102 Drum Filter (1000 μm)
F-103 Drum Filter (1000 μm)

V-101 Primary Sump
V-102 Secondary Sump
V-103 Secondary Sump

P-101 Primary Pump
P-102 Primary Pump
P-103 Primary Pump
P-104 Primary Pump

T-101 Abalone Tanks
T-102 Hatchery Tanks Unheated
T-103 Hatchery Tanks Heated
T-104 Hatchery Cold Water Tank
T-105 Hatchery Heated Water Tank

HP-101 Primary Pump
HP-102 Primary Pump
HP-103 Primary Pump
HP-104 Primary Pump

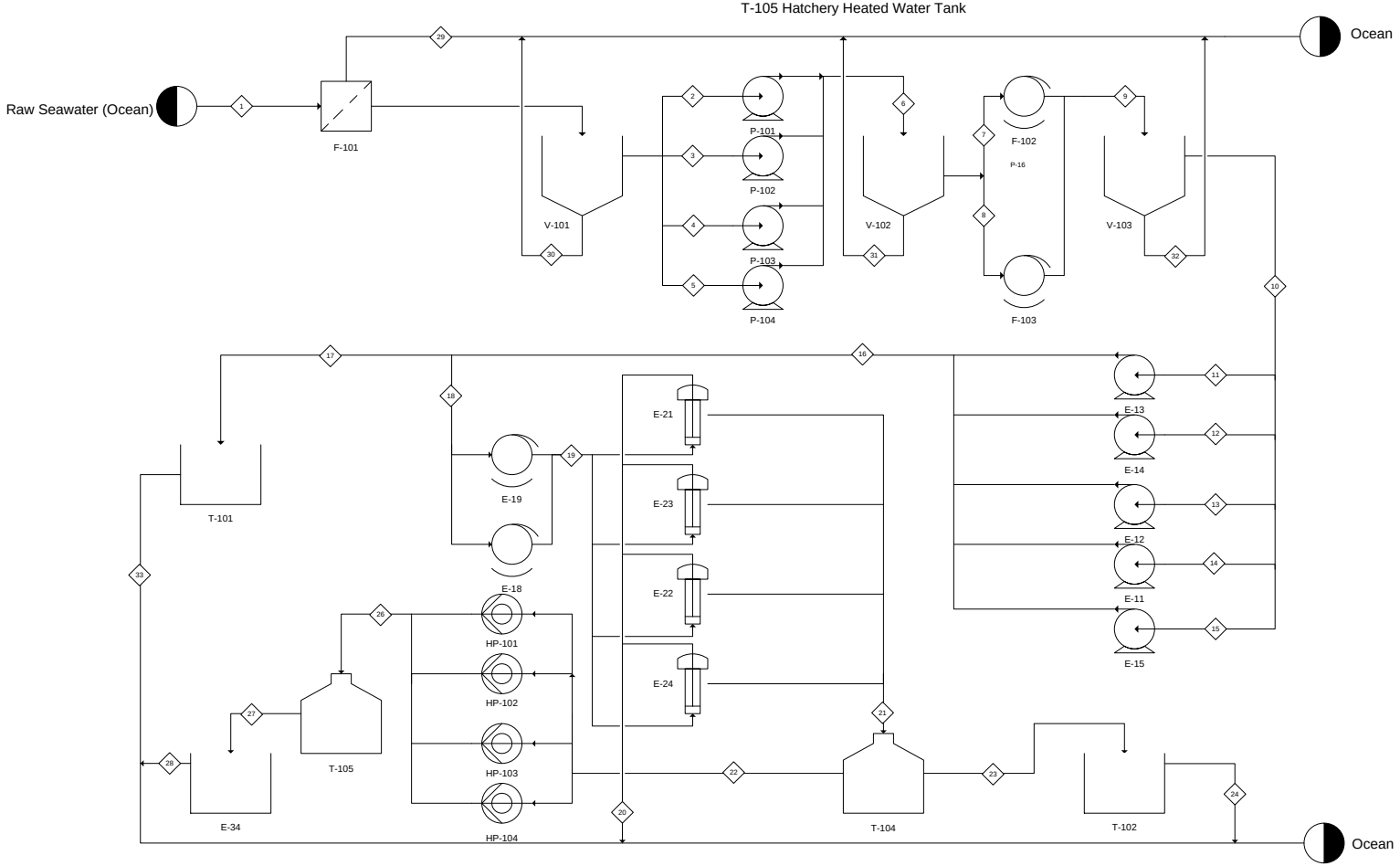


Figure B.1.2 *– Process flow diagram (PFD) of a typical South African abalone farm*

B.2 ULTRA-FILTRATION

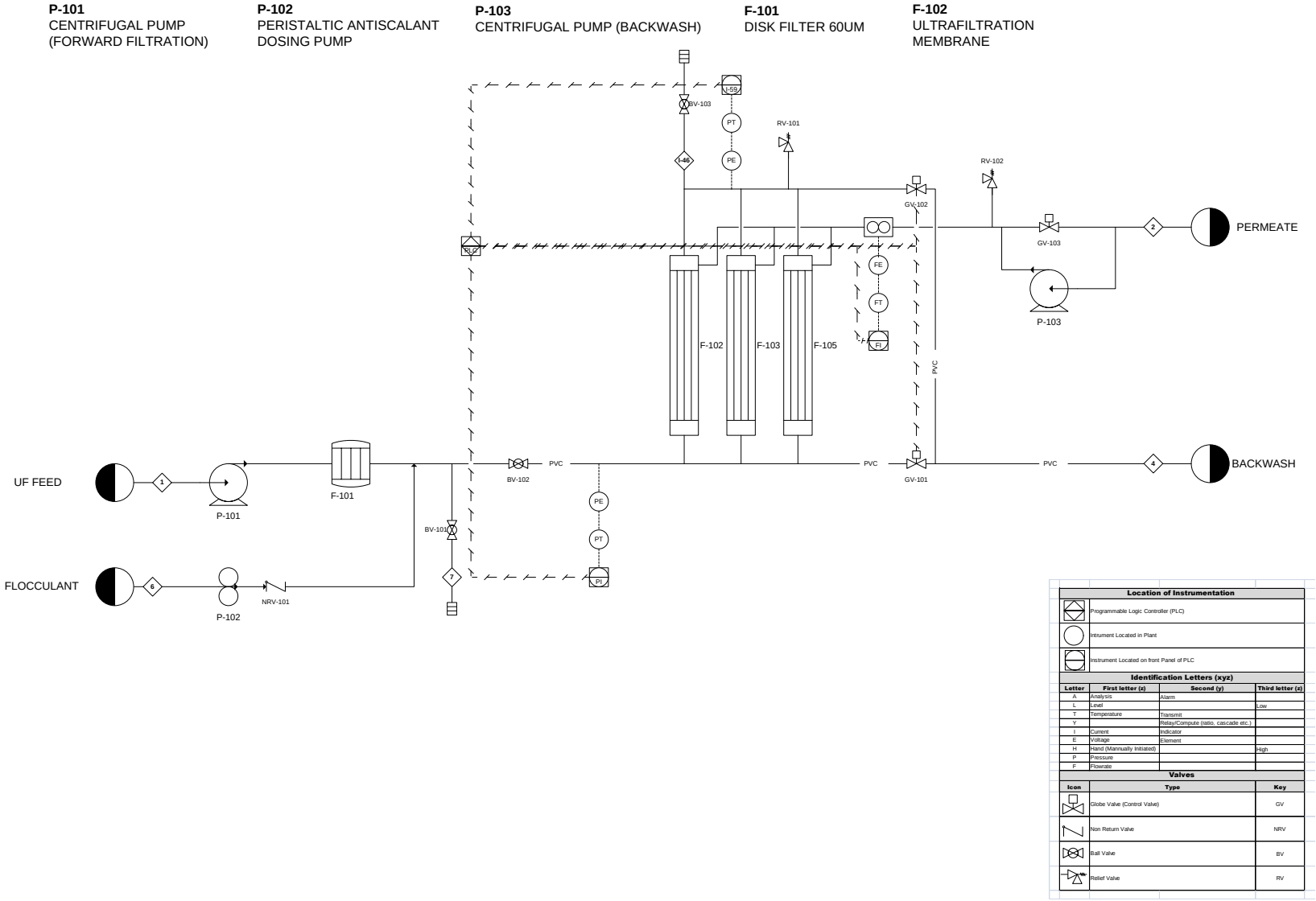
Figure B2.1 shows on top the entrance to the building containing the SWRO Desalination Pilot Plant and in the bottom left and right the gulley from where the effluent is to the buffer tank feeding the ultrafiltration unit.

Figure B.2.1 *- SWRO pilot pant building and intake*

Figure B2.2 presents the ultrafiltration unit. Top left is a photograph of the unit, top right is a close-up of the manifold that collects permeate, bottom left is a close-up of the disc filter and feed pump and bottom right is the backwash pump and the pipe flocculator.

Figure B.2.2 *– Ultrafiltration plot pant*

The P&ID of the ultrafiltration pilot plant is presented in Figure B2.3.



Location of Instrumentation	
	Programmable Logic Controller (PLC)
	Inturment Located in Plant
	Instrument Located on front Panel of PLC

Identification Letters (xyz)			
Letter	First letter (x)	Second (y)	Third letter (z)
A	Analysis	Alarm	
L	Level		Low
T	Temperature	Transmit	
V		Relay/Compute (ratio, cascade etc.)	
I	Current	Indicator	
E	Voltage	Element	
H	Hand (Mannually Initiated)		High
P	Pressure		
F	Flowrate		

Valves		
Icon	Type	Key
	Globe Valve (Control Valve)	GV
	Non Return Valve	NRV
	Ball Valve	BV
	Relief Valve	RV

Figure B.2.3 *– Ultra-filtration piping and instrumentation diagram*

B.3 REVERSE OSMOSIS

The reverse osmosis pilot unit is situated right opposite of the ultrafiltration pilot plant (on the left hand side in the photograph) and is presented here in Figure B3.1.

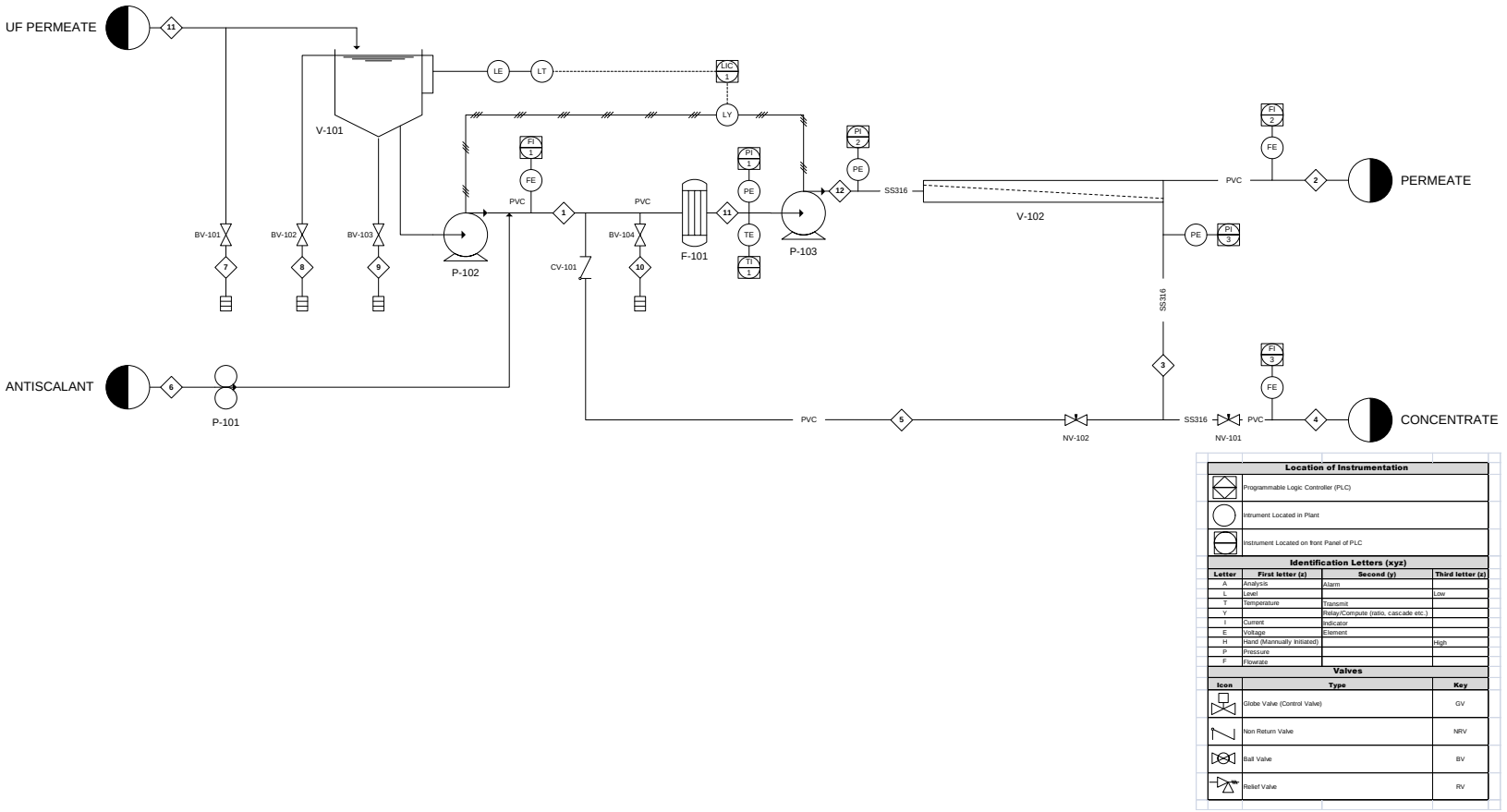
Figure B.3.1 *- Reverse osmosis pilot plant*

The P&ID for the reverse osmosis pilot plant is presented in Figure B3.2.

B.4 MFI EQUIPMENT

Figure B.4 presents the equipment for the measuring $MFI_{0.45}$; the top photo shows the frame and pump with recycle system built to control the pressure and reduce the amount of feed water required for $MFI_{0.45}$ measurement; the bottom left photo shows the filter holder; the two bottom right photos shows the parts of the filter holder and a filter after use in a $MFI_{0.45}$ measurement – notice the foulants on the white membrane.

P-101	P-102	V-101	F-101	P-102	V-102
DOSING PUMP	CENTRIFUGAL PUMP	FEED WATER TANK	CARTRIDGE FILTER	POSITIVE DISPLACEMENT PUMP	RO PRESSURE VESSEL



Location of Instrumentation	
	Programmable Logic Controller (PLC)
	Intrument Located in Plant
	Instrument Located on front Panel of PLC

Identification Letters (xyz)			
Letter	First letter (z)	Second (y)	Third letter (z)
A	Analysis	Alarm	
L	Level		Low
T	Temperature	Transmit	
Y		Relay/Compute (ratio, cascade etc.)	
I	Current	Indicator	
E	Voltage	Element	
H	Hand (Mannually Initiated)		High
P	Pressure		
F	Flowrate		

Valves		
Icon	Type	Key
	Globe Valve (Control Valve)	GV
	Non Return Valve	NRV
	Ball Valve	BV
	Relief Valve	RV

Figure B.3.2 *– Reverse osmosis piping and instrumentation diagram*

Figure B.4 *– $MFI_{0.45}$ equipment*

C. DATA

C.1 WATER CHARACTERISATION - CONVENTIONAL TANK CONFIGURATION

The results for the water characterisation parameters measured for the forty abalone tanks from October 2011 to April 2012 are summarised in this section Appendix C.

C.1.1 Temperature

Table C.1.1 (a)-(d) *– Abalone tank temperature*

Site	Timestamp		Temperature (°C)	
	IN	OUT	IN	OUT
122A1	2011/10/19 09:26	2011/09/27 10:14	15.4	15.2
122A2	2011/10/19 09:29	2011/09/27 10:14	15.4	15.2
122A3	2011/10/19 09:32	2011/09/27 10:14	15.4	15.2
122A4	2011/10/19 09:35	2011/09/27 10:14	15.4	15.2
122A5	2011/10/19 09:38	2011/09/27 10:14	15.4	15.2
122A6	2011/10/19 09:41	2011/09/27 10:14	15.4	15.2
122A7	2011/10/19 09:45	2011/09/27 10:14	15.4	15.2
122A8	2011/10/19 09:48	2011/09/27 10:14	15.4	15.2
122A9	2011/10/19 09:52	2011/09/27 10:14	15.5	15.2
122A10	2011/10/19 09:55	2011/09/27 10:14	15.5	15.1
122B1	2011/10/19 10:02	2011/09/27 10:14	15.5	15.3
122B2	2011/10/19 10:04	2011/09/27 10:14	15.5	15.3
122B3	2011/10/19 10:08	2011/09/27 10:14	15.5	15.3
122B4	2011/10/19 10:11	2011/09/27 10:14	15.5	15.3
122B5	2011/10/19 10:15	2011/09/27 10:14	15.5	15.3
122B6	2011/10/19 10:20	2011/09/27 10:14	15.5	15.3
122B7	2011/10/19 10:23	2011/09/27 10:14	15.5	15.3
122B8	2011/10/19 10:26	2011/09/27 10:14	15.5	15.3
122B9	2011/10/19 10:30	2011/09/27 10:14	15.5	15.3
122B10	2011/10/19 10:32	2011/09/27 10:14	15.5	15.3
123A1	2011/10/19 11:45	2011/09/27 10:14	15.6	15.5
123A2	2011/10/19 11:48	2011/09/27 10:14	15.7	15.4
123A3	2011/10/19 11:52	2011/09/27 10:14	15.6	15.4
123A4	2011/10/19 11:55	2011/09/27 10:14	15.6	15.4
123A5	2011/10/19 11:59	2011/09/27 10:14	15.7	15.4
123A6	2011/10/19 12:02	2011/09/27 10:14	15.7	15.4
123A7	2011/10/19 12:05	2011/09/27 10:14	15.7	15.4
123A8	2011/10/19 12:13	2011/09/27 10:14	15.8	15.4
123A9	2011/10/19 12:15	2011/09/27 10:14	15.8	15.4
123A10	2011/10/19 12:18	2011/09/27 10:14	15.8	15.4
123B1	2011/10/19 12:21	2011/09/27 10:14	15.7	15.7
123B2	2011/10/19 12:23	2011/09/27 10:14	15.7	15.6
123B3	2011/10/19 12:26	2011/09/27 10:14	15.7	15.7
123B4	2011/10/19 12:28	2011/09/27 10:14	15.7	15.7
123B5	2011/10/19 12:30	2011/09/27 10:14	15.7	15.7
123B6	2011/10/19 12:32	2011/09/27 10:14	15.7	15.7
123B7	2011/10/19 12:34	2011/09/27 10:14	15.8	15.5
123B8	2011/10/19 12:37	2011/09/27 10:14	15.8	15.5
123B9	2011/10/19 12:40	2011/09/27 10:14	15.8	15.5
123B10	2011/10/19 12:42	2011/09/27 10:14	15.8	15.5

Site	Timestamp		Temperature (°C)	
	IN	OUT	IN	OUT
122A1	2012/01/18 09:37	2012/01/18 09:39	15.3	15.5
122A2	2012/01/18 09:40	2012/01/18 09:41	15.4	15.5
122A3	2012/01/18 09:42	2012/01/18 09:43	15.4	15.5
122A4	2012/01/18 09:44	2012/01/18 09:45	15.4	15.5
122A5	2012/01/18 09:46	2012/01/18 09:47	15.5	15.6
122A6	2012/01/18 09:49	2012/01/18 09:50	15.4	15.5
122A7	2012/01/18 09:51	2012/01/18 09:51	15.4	15.5
122A8	2012/01/18 09:54	2012/01/18 09:55	15.5	15.5
122A9	2012/01/18 09:59	2012/01/18 10:00	15.5	15.6
122A10	2012/01/18 10:02	2012/01/18 10:03	15.6	15.8
122B1	2012/01/18 10:23	2012/01/18 10:25	15.5	15.6
122B2	2012/01/18 10:26	2012/01/18 10:27	15.4	15.7
122B3	2012/01/18 10:28	2012/01/18 10:30	15.4	15.7
122B4	2012/01/18 10:31	2012/01/18 10:32	15.4	15.7
122B5	2012/01/18 10:33	2012/01/18 10:35	15.5	15.7
122B6	2012/01/18 10:36	2012/01/18 10:38	15.5	15.7
122B7	2012/01/18 10:40	2012/01/18 10:41	15.6	15.7
122B8	2012/01/18 10:43	2012/01/18 10:44	15.8	15.7
122B9	2012/01/18 10:45	2012/01/18 10:47	15.7	15.8
122B10	2012/01/18 10:48	2012/01/18 10:49	15.9	15.9
123A1	2012/01/18 10:59	2012/01/18 11:00	15.8	15.8
123A2	2012/01/18 11:02	2012/01/18 11:03	15.7	15.8
123A3	2012/01/18 11:05	2012/01/18 11:07	15.8	15.9
123A4	2012/01/18 11:08	2012/01/18 11:09	15.8	16
123A5	2012/01/18 11:11	2012/01/18 11:12	15.9	15.9
123A6	2012/01/18 11:13	2012/01/18 11:15	15.9	15.9
123A7	2012/01/18 11:16	2012/01/18 11:17	16	16
123A8	2012/01/18 11:18	2012/01/18 11:20	16.1	16
123A9	2012/01/18 11:21	2012/01/18 11:22	16.1	16
123A10	2012/01/18 11:24	2012/01/18 11:25	16.3	16.2
123B1	2012/01/18 11:35	2012/01/18 11:36	16.3	16
123B2	2012/01/18 11:38	2012/01/18 11:39	16.3	16.2
123B3	2012/01/18 11:40	2012/01/18 11:41	16.3	16.1
123B4	2012/01/18 11:42	2012/01/18 11:43	16.3	16.1
123B5	2012/01/18 11:45	2012/01/18 11:46	16.4	16.1
123B6	2012/01/18 11:47	2012/01/18 11:49	16.3	16.1
123B7	2012/01/18 11:50	2012/01/18 11:51	16.4	16.2
123B8	2012/01/18 11:52	2012/01/18 11:53	16.4	16.2
123B9	2012/01/18 11:55	2012/01/18 11:56	16.6	16.2
123B10	2012/01/18 11:58	2012/01/18 11:59	16.7	16.3

Site	Timestamp		Temperature (°C)	
	IN	OUT	IN	OUT
122A1	2012/01/23 12:23	2012/01/23 12:25	19.7	19.6
122A2	2012/01/23 12:26	2012/01/23 12:28	19.6	19.5
122A3	2012/01/23 12:29	2012/01/23 12:31	19.6	19.5
122A4	2012/01/23 12:37	2012/01/23 12:39	19.8	19.5
122A5	2012/01/23 12:43	2012/01/23 12:46	19.7	19.5
122A6	2012/01/23 12:48	2012/01/23 12:49	19.6	19.5
122A7	2012/01/23 12:51	2012/01/23 12:52	19.6	19.6
122A8	2012/01/23 12:54	2012/01/23 12:55	19.6	19.5
122A9	2012/01/23 12:57	2012/01/23 12:59	19.7	19.5
122A10	2012/01/23 13:01	2012/01/23 13:02	19.6	19.5
122B1	2012/01/23 13:06	2012/01/23 13:07	19.6	19.6
122B2	2012/01/23 13:08	2012/01/23 13:10	19.6	19.6
122B3	2012/01/23 13:12	2012/01/23 13:13	19.6	19.6
122B4	2012/01/23 13:15	2012/01/23 13:16	19.6	19.6
122B5	2012/01/23 13:18	2012/01/23 13:19	19.6	19.6
122B6	2012/01/23 13:21	2012/01/23 13:22	19.6	19.6
122B7	2012/01/23 13:23	2012/01/23 13:25	19.6	19.6
122B8	2012/01/23 13:27	2012/01/23 13:28	19.6	19.6
122B9	2012/01/23 13:30	2012/01/23 13:31	19.7	19.6
122B10	2012/01/23 13:32	2012/01/23 13:34	19.7	19.6
123A1	2012/01/23 14:07	2012/01/23 14:08	19.8	19.7
123A2	2012/01/23 14:10	2012/01/23 14:12	19.7	19.7
123A3	2012/01/23 14:14	2012/01/23 14:15	19.7	19.7
123A4	2012/01/23 14:17	2012/01/23 14:23	19.7	19.7
123A5	2012/01/23 14:24	2012/01/23 14:26	19.7	19.7
123A6	2012/01/23 14:30	2012/01/23 14:32	19.7	19.7
123A7	2012/01/23 14:35	2012/01/23 14:37	19.7	19.7
123A8	2012/01/23 14:38	2012/01/23 14:40	19.7	19.7
123A9	2012/01/23 14:43	2012/01/23 14:44	19.7	19.7
123A10	2012/01/23 14:46	2012/01/23 14:47	19.8	19.8
123B1	2012/01/23 14:55	2012/01/23 14:56	19.8	19.8
123B2	2012/01/23 15:00	2012/01/23 15:02	19.7	19.8
123B3	2012/01/23 15:03	2012/01/23 15:05	19.7	19.8
123B4	2012/01/23 15:18	2012/01/23 16:11	19.8	19.9
123B5	2012/01/23 16:13	2012/01/23 16:15	19.8	19.9
123B6	2012/01/23 16:17	2012/01/23 16:19	19.8	19.9
123B7	2012/01/23 16:21	2012/01/23 16:22	19.8	19.9
123B8	2012/01/23 16:26	2012/01/23 16:27	19.8	19.9
123B9	2012/01/23 16:36	2012/01/23 16:38	20.2	19.9
123B10	2012/01/23 16:39	2012/01/23 16:40	19.8	20.1

Site	Timestamp		Temperature (°C)	
	IN	OUT	IN	OUT
122A1	2012/03/20 11:40	2012/03/20 14:21	18.6	19.4
122A2	2012/03/20 11:42	2012/03/20 14:22	18.6	19.1
122A3	2012/03/20 11:44	2012/03/20 14:24	18.6	19.1
122A4	2012/03/20 11:46	2012/03/20 14:26	18.6	19.1
122A5	2012/03/20 11:49	2012/03/20 14:27	18.6	19.1
122A6	2012/03/20 11:50	2012/03/20 14:28	18.7	19
122A7	2012/03/20 11:53	2012/03/20 14:30	18.7	19
122A8	2012/03/20 11:55	2012/03/20 14:31	18.7	19
122A9	2012/03/20 11:57	2012/03/20 14:31	18.7	19.1
122A10	2012/03/20 11:59	2012/03/20 14:32	18.8	19.1
122B1	2012/03/20 12:11	2012/03/20 15:08	18.6	19.2
122B2	2012/03/20 12:13	2012/03/20 15:09	18.6	19.1
122B3	2012/03/20 12:14	2012/03/20 15:10	18.6	19.2
122B4	2012/03/20 12:15	2012/03/20 15:11	18.6	19.2
122B5	2012/03/20 12:17	2012/03/20 15:12	18.6	19.4
122B6	2012/03/20 12:18	2012/03/20 15:13	18.7	19.2
122B7	2012/03/20 12:19	2012/03/20 15:13	18.7	19.2
122B8	2012/03/20 12:21	2012/03/20 15:14	18.7	19.2
122B9	2012/03/20 12:22	2012/03/20 15:15	18.7	19.3
122B10	2012/03/20 12:26	2012/03/20 15:16	18.8	19.2
123A1	2012/03/20 12:55	2012/03/20 14:37	18.6	19.2
123A2	2012/03/20 12:54	2012/03/20 14:38	18.6	19
123A3	2012/03/20 12:53	2012/03/20 14:39	18.6	19.1
123A4	2012/03/20 12:52	2012/03/20 14:41	18.7	19.1
123A5	2012/03/20 12:51	2012/03/20 14:42	18.6	19.1
123A6	2012/03/20 12:50	2012/03/20 14:43	18.7	19.1
123A7	2012/03/20 12:49	2012/03/20 14:44	18.7	19.2
123A8	2012/03/20 12:47	2012/03/20 14:46	18.7	19.2
123A9	2012/03/20 12:46	2012/03/20 14:47	18.7	19.2
123A10	2012/03/20 12:45	2012/03/20 14:48	18.8	19.1
123B1	2012/03/20 12:32	2012/03/20 14:51	18.7	19.5
123B2	2012/03/20 12:33	2012/03/20 14:52	18.7	19.4
123B3	2012/03/20 12:34	2012/03/20 14:53	18.7	19.3
123B4	2012/03/20 12:35	2012/03/20 14:54	18.7	19.2
123B5	2012/03/20 12:36	2012/03/20 14:54	18.7	19.4
123B6	2012/03/20 12:37	2012/03/20 14:55	18.7	19.3
123B7	2012/03/20 12:38	2012/03/20 14:56	18.7	19.4
123B8	2012/03/20 12:39	2012/03/20 14:57	18.8	19.4
123B9	2012/03/20 12:40	2012/03/20 14:57	18.8	19.4
123B10	2012/03/20 12:42	2012/03/20 14:58	18.8	19.4

Table C.1.1 (e)-(h) *– Abalone tank temperature*

Site	Timestamp		Temperature (°C)	
	IN	OUT	IN	OUT
122A1	2012/03/27 10:42	2012/03/27 10:55	12.1	12.3
122A2	2012/03/27 10:43	2012/03/27 10:56	12	12.3
122A3	2012/03/27 10:44	2012/03/27 10:57	12	12.3
122A4	2012/03/27 10:45	2012/03/27 10:58	12.1	12.2
122A5	2012/03/27 10:47	2012/03/27 10:59	12.1	12.4
122A6	2012/03/27 10:48	2012/03/27 11:01	12.1	12.3
122A7	2012/03/27 10:49	2012/03/27 11:01	12.1	12.4
122A8	2012/03/27 10:50	2012/03/27 11:02	12.1	12.4
122A9	2012/03/27 10:52	2012/03/27 11:03	12.2	12.5
122A10	2012/03/27 10:53	2012/03/27 11:04	12.3	12.5
122B1	2012/03/27 11:06	2012/03/27 11:20	12.1	12.4
122B2	2012/03/27 11:08	2012/03/27 11:21	12.1	12.4
122B3	2012/03/27 11:09	2012/03/27 11:22	12	12.4
122B4	2012/03/27 11:11	2012/03/27 11:23	12.1	12.4
122B5	2012/03/27 11:12	2012/03/27 11:23	12.1	12.4
122B6	2012/03/27 11:13	2012/03/27 11:24	12.1	12.4
122B7	2012/03/27 11:14	2012/03/27 11:25	12.1	12.4
122B8	2012/03/27 11:15	2012/03/27 11:26	12.1	12.5
122B9	2012/03/27 11:16	2012/03/27 11:27	12.1	12.5
122B10	2012/03/27 11:17	2012/03/27 11:28	12.2	12.6
123A1	2012/03/27 11:44	2012/03/27 11:56	12	12.5
123A2	2012/03/27 11:45	2012/03/27 11:57	12	12.4
123A3	2012/03/27 11:47	2012/03/27 11:57	12.1	12.5
123A4	2012/03/27 11:48	2012/03/27 11:58	12.1	12.5
123A5	2012/03/27 11:49	2012/03/27 11:59	12.1	12.6
123A6	2012/03/27 11:50	2012/03/27 12:01	12.1	12.4
123A7	2012/03/27 11:51	2012/03/27 12:02	12.1	12.5
123A8	2012/03/27 11:52	2012/03/27 12:03	12.1	12.6
123A9	2012/03/27 11:53	2012/03/27 12:04	12.1	12.7
123A10	2012/03/27 11:54	2012/03/27 12:04	12.2	13
123B1	2012/03/27 14:15	2012/03/27 14:29	12.8	12.5
123B2	2012/03/27 14:16	2012/03/27 14:30	12.7	12.7
123B3	2012/03/27 14:19	2012/03/27 14:30	12.8	12.6
123B4	2012/03/27 14:20	2012/03/27 14:31	12.8	12.5
123B5	2012/03/27 14:21	2012/03/27 14:32	12.9	12.6
123B6	2012/03/27 14:22	2012/03/27 14:52	12.9	12.7
123B7	2012/03/27 14:23	2012/03/27 14:53	13	12.7
123B8	2012/03/27 14:24	2012/03/27 14:53	13	12.7
123B9	2012/03/27 14:25	2012/03/27 14:54	13	12.6
123B10	2012/03/27 14:26	2012/03/27 14:55	13.1	12.8

Site	Timestamp		Temperature (°C)	
	IN	OUT	IN	OUT
122A1	2012/04/03 11:12	2012/04/03 11:25	15.2	15.5
122A2	2012/04/03 11:13	2012/04/03 11:27	15.2	15.4
122A3	2012/04/03 11:14	2012/04/03 11:28	15.2	15.5
122A4	2012/04/03 11:15	2012/04/03 11:29	15.2	15.4
122A5	2012/04/03 11:16	2012/04/03 11:30	15.3	15.5
122A6	2012/04/03 11:17	2012/04/03 11:32	15.3	15.5
122A7	2012/04/03 11:18	2012/04/03 11:33	15.3	15.5
122A8	2012/04/03 11:20	2012/04/03 11:34	15.3	15.4
122A9	2012/04/03 11:21	2012/04/03 11:35	15.3	15.5
122A10	2012/04/03 11:22	2012/04/03 11:36	15.3	15.5
122B1	2012/04/03 12:08	2012/04/03 12:20	15.2	15.5
122B2	2012/04/03 12:09	2012/04/03 12:21	15.2	15.5
122B3	2012/04/03 12:11	2012/04/03 12:22	15.2	15.5
122B4	2012/04/03 12:13	2012/04/03 12:23	15.2	15.5
122B5	2012/04/03 12:13	2012/04/03 12:23	15.3	15.5
122B6	2012/04/03 12:14	2012/04/03 12:24	15.2	15.5
122B7	2012/04/03 12:15	2012/04/03 12:25	15.3	15.5
122B8	2012/04/03 12:16	2012/04/03 12:26	15.3	15.6
122B9	2012/04/03 12:17	2012/04/03 12:26	15.3	15.6
122B10	2012/04/03 12:18	2012/04/03 12:27	15.4	15.6
123A1	2012/04/03 14:49	2012/04/03 14:59	17.2	16.6
123A2	2012/04/03 14:50	2012/04/03 15:00	17.1	16.8
123A3	2012/04/03 14:51	2012/04/03 15:01	17.1	16.6
123A4	2012/04/03 14:52	2012/04/03 15:02	17.1	16.5
123A5	2012/04/03 14:53	2012/04/03 15:03	17.1	16.6
123A6	2012/04/03 14:54	2012/04/03 15:04	17.1	16.7
123A7	2012/04/03 14:55	2012/04/03 15:05	17.2	16.7
123A8	2012/04/03 14:56	2012/04/03 15:05	17.2	16.5
123A9	2012/04/03 14:57	2012/04/03 15:06	17.2	16.7
123A10	2012/04/03 14:57	2012/04/03 15:07	17.3	16.6
123B1	2012/04/03 15:27	2012/04/03 15:51	17.5	17.7
123B2	2012/04/03 15:28	2012/04/03 15:52	17.4	17.5
123B3	2012/04/03 15:29	2012/04/03 15:53	17.4	17.5
123B4	2012/04/03 15:30	2012/04/03 15:53	17.5	17.6
123B5	2012/04/03 15:31	2012/04/03 15:54	17.5	17.6
123B6	2012/04/03 15:32	2012/04/03 15:55	17.5	17.6
123B7	2012/04/03 15:33	2012/04/03 15:56	17.5	17.6
123B8	2012/04/03 15:34	2012/04/03 15:57	17.5	17.7
123B9	2012/04/03 15:35	2012/04/03 15:57	17.5	17.6
123B10	2012/04/03 15:36	2012/04/03 15:58	17.5	17.8

Site	Timestamp		Temperature (°C)	
	IN	OUT	IN	OUT
122A1	2012/04/19 10:52	2012/04/19 11:16	14.7	14.9
122A2	2012/04/19 10:53	2012/04/19 11:17	14.7	14.9
122A3	2012/04/19 10:54	2012/04/19 11:17	14.7	14.9
122A4	2012/04/19 10:55	2012/04/19 11:18	14.7	14.9
122A5	2012/04/19 10:56	2012/04/19 11:19	14.7	14.9
122A6	2012/04/19 10:57	2012/04/19 11:20	14.7	14.9
122A7	2012/04/19 10:58	2012/04/19 11:21	14.7	14.9
122A8	2012/04/19 11:00	2012/04/19 11:22	14.7	14.9
122A9	2012/04/19 11:01	2012/04/19 11:22	14.7	14.9
122A10	2012/04/19 11:02	2012/04/19 11:24	14.8	15
122B1	2012/04/19 11:04	2012/04/19 11:25	14.7	14.9
122B2	2012/04/19 11:05	2012/04/19 11:26	14.7	14.9
122B3	2012/04/19 11:06	2012/04/19 11:27	14.7	14.9
122B4	2012/04/19 11:07	2012/04/19 11:28	14.7	14.9
122B5	2012/04/19 11:08	2012/04/19 11:28	14.7	14.9
122B6	2012/04/19 11:09	2012/04/19 11:29	14.7	14.9
122B7	2012/04/19 11:10	2012/04/19 11:29	14.8	15
122B8	2012/04/19 11:11	2012/04/19 11:30	14.8	14.9
122B9	2012/04/19 11:12	2012/04/19 11:31	14.8	14.9
122B10	2012/04/19 11:13	2012/04/19 11:31	14.8	15
123A1	2012/04/19 11:41	2012/04/19 12:10	14.8	15
123A2	2012/04/19 11:41	2012/04/19 12:11	14.8	14.9
123A3	2012/04/19 11:42	2012/04/19 12:11	14.8	15
123A4	2012/04/19 11:43	2012/04/19 12:12	14.8	15
123A5	2012/04/19 11:44	2012/04/19 12:13	14.8	15
123A6	2012/04/19 11:45	2012/04/19 12:13	14.8	14.9
123A7	2012/04/19 11:46	2012/04/19 12:14	14.8	15.1
123A8	2012/04/19 11:47	2012/04/19 12:23	14.8	15
123A9	2012/04/19 11:48	2012/04/19 12:23	14.8	15.1
123A10	2012/04/19 11:49	2012/04/19 12:24	14.9	15.1
123B1	2012/04/19 11:53	2012/04/19 12:25	14.8	15.1
123B2	2012/04/19 11:54	2012/04/19 12:26	14.8	15.1
123B3	2012/04/19 11:55	2012/04/19 12:26	14.9	15
123B4	2012/04/19 11:56	2012/04/19 12:27	14.9	15
123B5	2012/04/19 11:57	2012/04/19 12:28	14.9	15.1
123B6	2012/04/19 11:58	2012/04/19 12:28	14.9	15.1
123B7	2012/04/19 11:59	2012/04/19 12:29	14.9	15.1
123B8	2012/04/19 11:59	2012/04/19 12:29	14.9	15.1
123B9	2012/04/19 12:00	2012/04/19 12:30	14.9	15.1
123B10	2012/04/19 12:01	2012/04/19 12:31	15	15.2

Site	Timestamp		Temperature (°C)	
	IN	OUT	IN	OUT
122A1	2012/04/26 11:00	2012/04/26 12:57	11	11.4
122A2	2012/04/26 11:01	2012/04/26 12:57	11	11.3
122A3	2012/04/26 11:02	2012/04/26 12:59	11	11.3
122A4	2012/04/26 11:04	2012/04/26 12:59	11	11.3
122A5	2012/04/26 11:05	2012/04/26 13:00	11	11.4
122A6	2012/04/26 11:06	2012/04/26 13:01	11	11.4
122A7	2012/04/26 11:07	2012/04/26 13:02	11	11.4
122A8	2012/04/26 11:08	2012/04/26 13:03	11.1	11.4
122A9	2012/04/26 11:10	2012/04/26 13:04	11.1	11.4
122A10	2012/04/26 11:11	2012/04/26 13:04	11.1	11.5
122B1	2012/04/26 11:25	2012/04/26 13:06	11	11.3
122B2	2012/04/26 11:26	2012/04/26 13:07	11	11.3
122B3	2012/04/26 11:28	2012/04/26 13:08	11	11.4
122B4	2012/04/26 11:29	2012/04/26 13:09	11	11.4
122B5	2012/04/26 11:31	2012/04/26 13:10	11	11.4
122B6	2012/04/26 11:32	2012/04/26 13:10	11	11.5
122B7	2012/04/26 11:33	2012/04/26 13:11	11.1	11.5
122B8	2012/04/26 11:34	2012/04/26 13:12	11.1	11.5
122B9	2012/04/26 11:35	2012/04/26 13:12	11.1	11.5
122B10	2012/04/26 11:36	2012/04/26 13:13	11.1	11.5
123A1	2012/04/26 11:41	2012/04/26 13:24	11	11.4
123A2	2012/04/26 11:42	2012/04/26 13:24	11	11.3
123A3	2012/04/26 11:43	2012/04/26 13:25	11	11.4
123A4	2012/04/26 11:44	2012/04/26 13:26	11	11.4
123A5	2012/04/26 11:46	2012/04/26 13:27	11.1	11.5
123A6	2012/04/26 11:47	2012/04/26 13:28	11.1	11.4
123A7	2012/04/26 11:48	2012/04/26 13:28	11.1	11.7
123A8	2012/04/26 11:49	2012/04/26 13:29	11.1	11.5
123A9	2012/04/26 11:50	2012/04/26 13:30	11.1	11.6
123A10	2012/04/26 11:51	2012/04/26 13:31	11.1	11.6
123B1	2012/04/26 11:54	2012/04/26 13:32	11	11.5
123B2	2012/04/26 11:55	2012/04/26 13:33	11	11.6
123B3	2012/04/26 11:56	2012/04/26 13:34	11	11.5
123B4	2012/04/26 11:57	2012/04/26 13:35	11	11.5
123B5	2012/04/26 11:59	2012/04/26 13:35	11	11.7
123B6	2012/04/26 12:00	2012/04/26 13:37	11.1	11.6
123B7	2012/04/26 12:01	2012/04/26 13:37	11.1	11.7
123B8	2012/04/26 12:02	2012/04/26 13:38	11.1	11.7
123B9	2012/04/26 12:02	2012/04/26 13:39	11.1	11.7
123B10	2012/04/26 12:03	2012/04/26 13:39	11.1	11.9

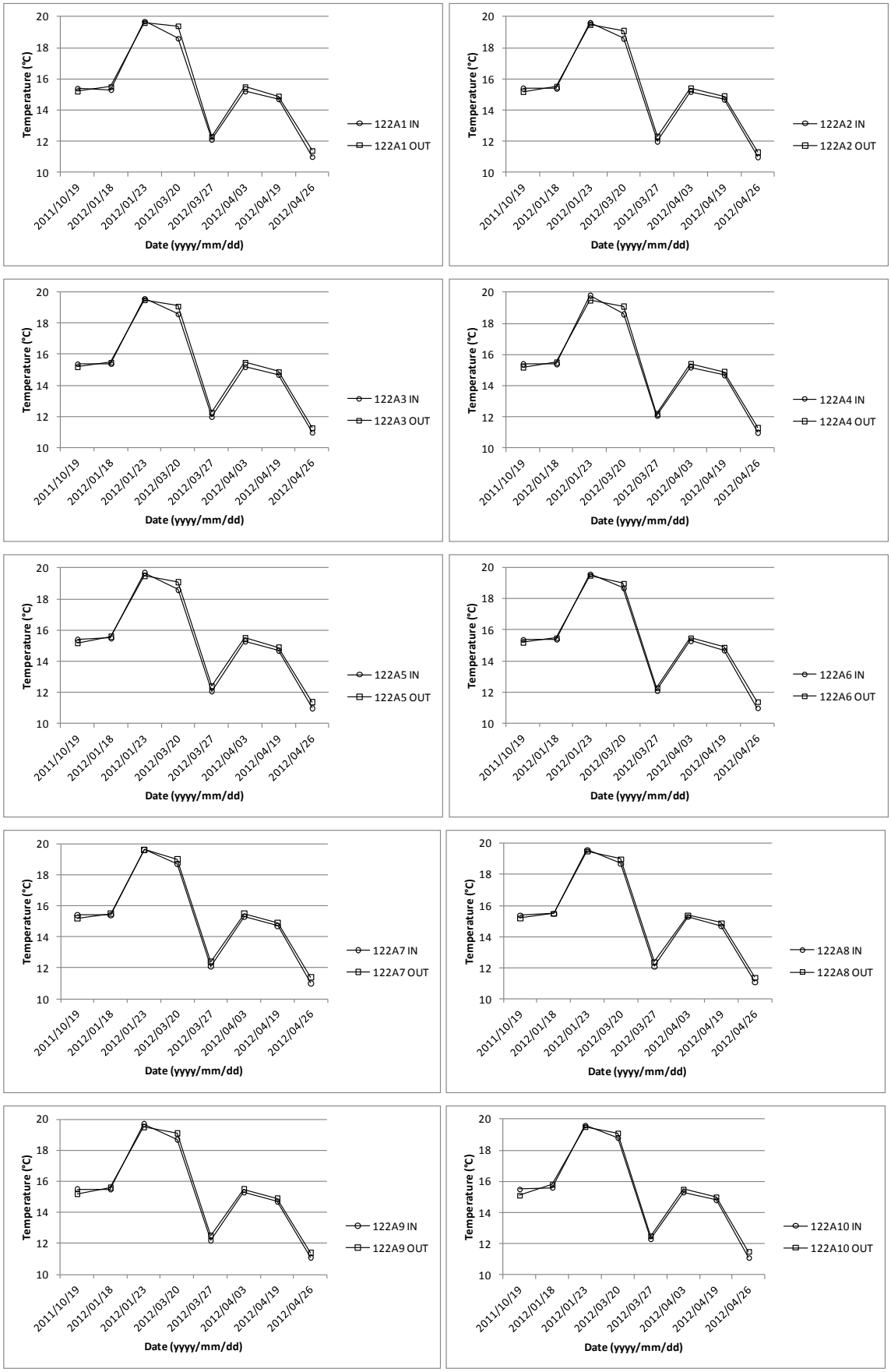


Figure C.1.1.1 *– Row 122A abalone tank temperature*

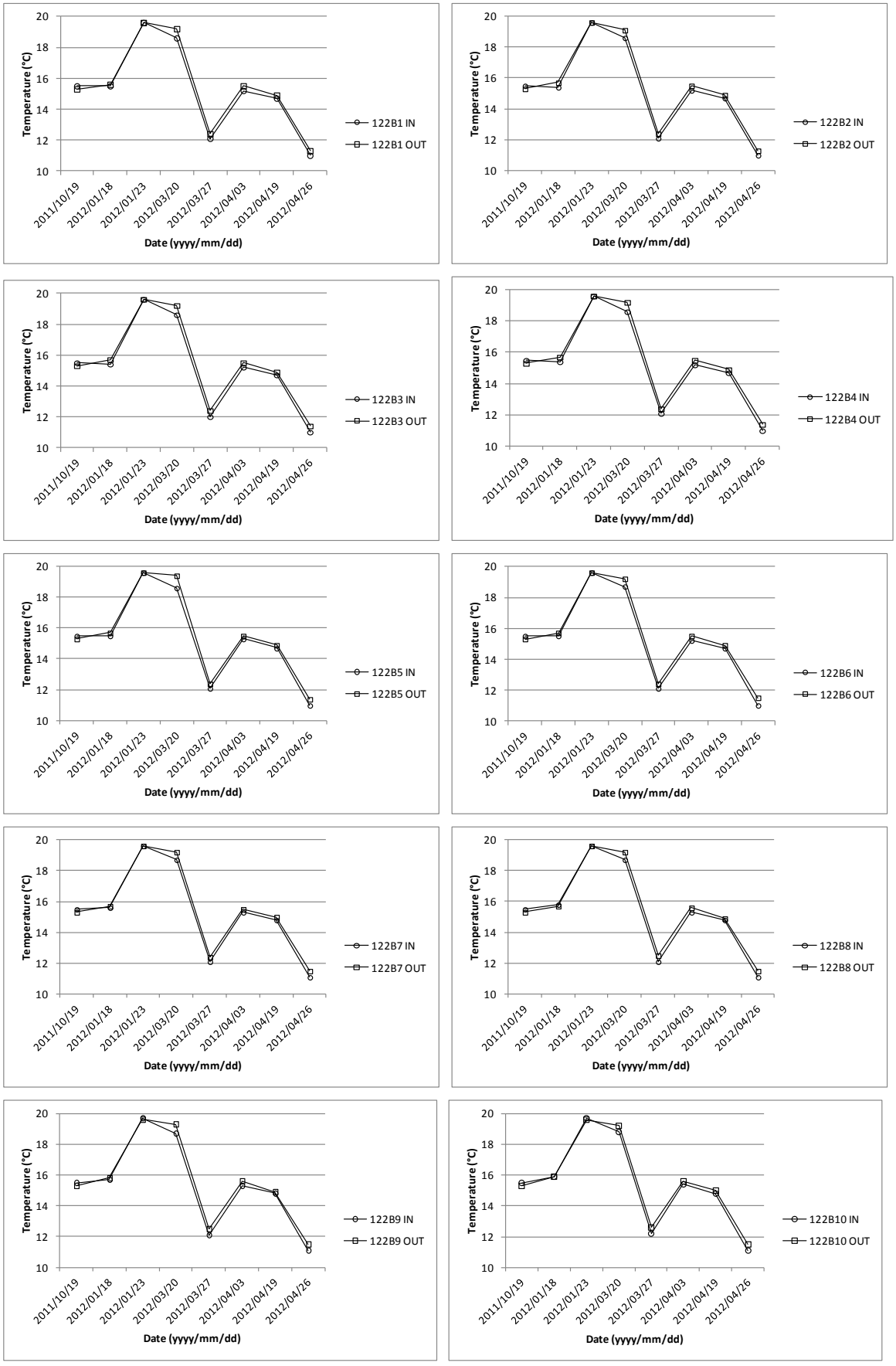


Figure C.1.2.2 *– Row 122B abalone tank temperature*

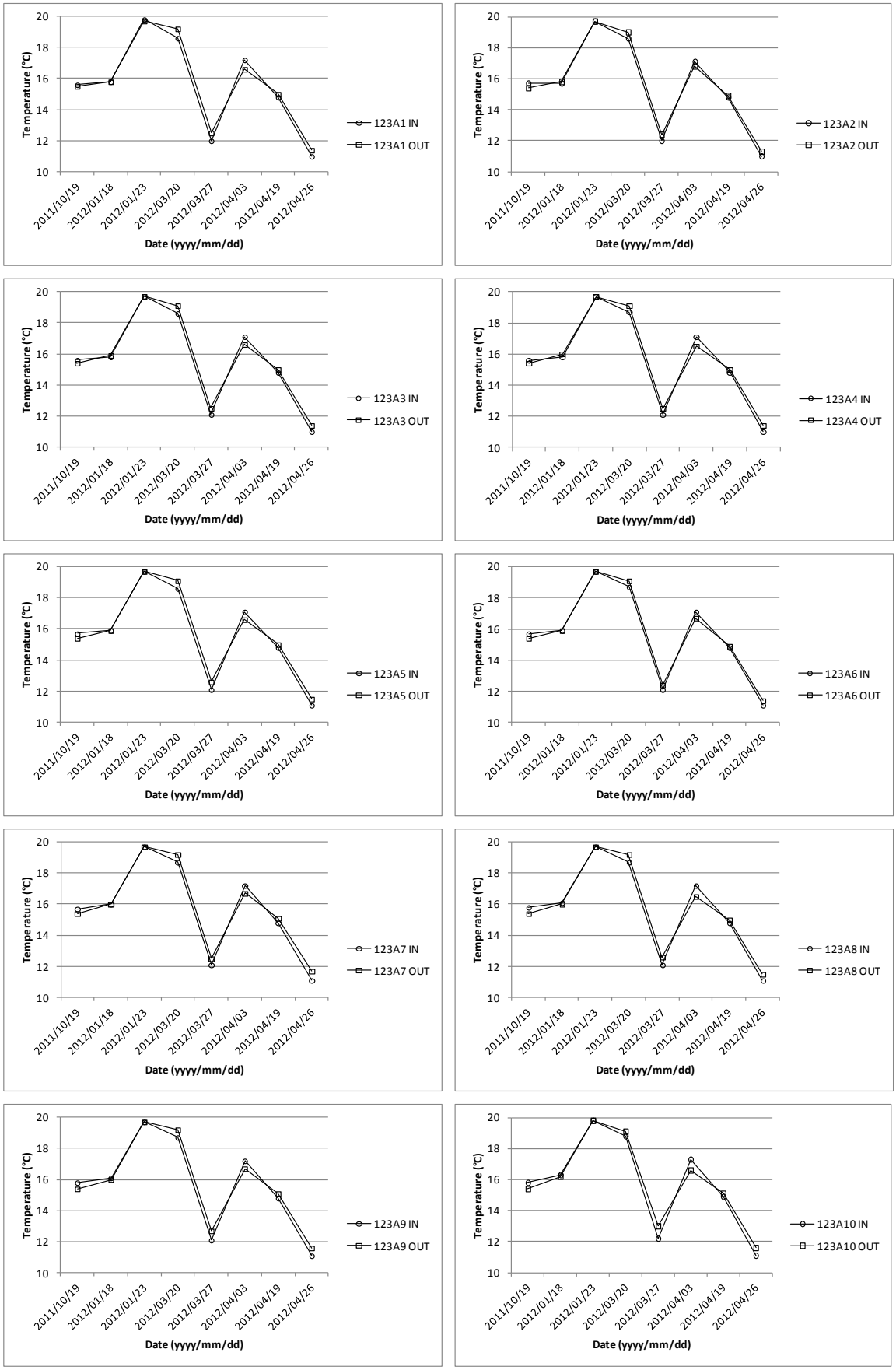


Figure C.1.2.3 *– Row 123A abalone tank temperature*

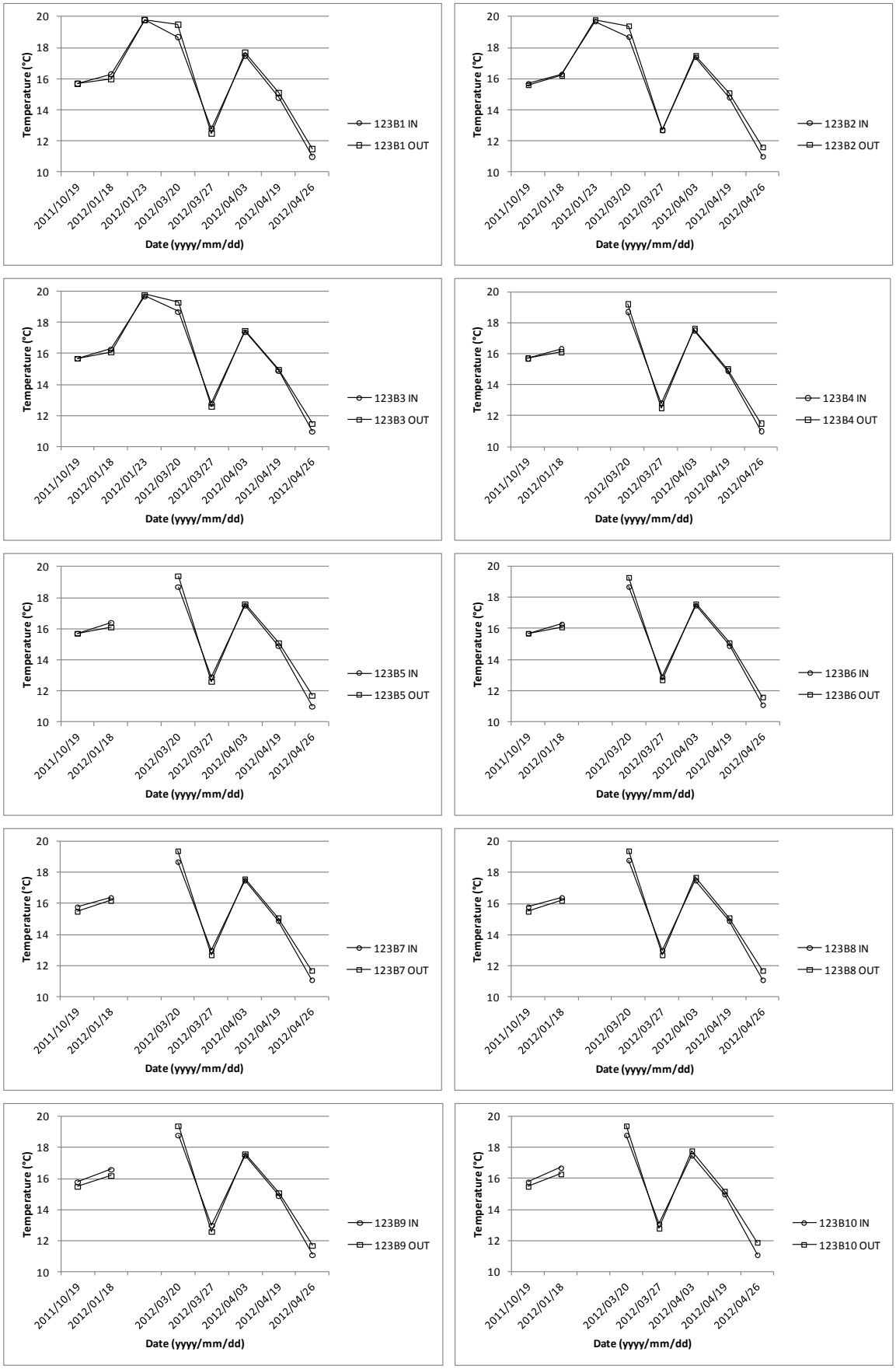


Figure C.1.2.4 *– Row 123B abalone tank temperature*

C.1.2 Specific Conductivity

Table C.1.2 (a)-(d) *– Abalone tank specific conductivity*

Site	Timestamp		Specific Conductance (uS/cm)	
	IN	OUT	IN	OUT
122A1	2011/10/19 09:26	2011/09/27 10:14	52697	52653
122A2	2011/10/19 09:29	2011/09/27 10:14	52681	52650
122A3	2011/10/19 09:32	2011/09/27 10:14	52658	52657
122A4	2011/10/19 09:35	2011/09/27 10:14	52650	52660
122A5	2011/10/19 09:38	2011/09/27 10:14	52598	52659
122A6	2011/10/19 09:41	2011/09/27 10:14	52696	52642
122A7	2011/10/19 09:45	2011/09/27 10:14	52508	52185
122A8	2011/10/19 09:48	2011/09/27 10:14	52678	52726
122A9	2011/10/19 09:52	2011/09/27 10:14	52695	52669
122A10	2011/10/19 09:55	2011/09/27 10:14	52720	52676
122B1	2011/10/19 10:02	2011/09/27 10:14	52720	52707
122B2	2011/10/19 10:04	2011/09/27 10:14	52633	52631
122B3	2011/10/19 10:08	2011/09/27 10:14	52683	52654
122B4	2011/10/19 10:11	2011/09/27 10:14	52694	52710
122B5	2011/10/19 10:15	2011/09/27 10:14	52727	52716
122B6	2011/10/19 10:20	2011/09/27 10:14	52505	52715
122B7	2011/10/19 10:23	2011/09/27 10:14	52739	52688
122B8	2011/10/19 10:26	2011/09/27 10:14	52724	52697
122B9	2011/10/19 10:30	2011/09/27 10:14	52647	52720
122B10	2011/10/19 10:32	2011/09/27 10:14	52623	52688
123A1	2011/10/19 11:45	2011/09/27 10:14	52703	52228
123A2	2011/10/19 11:48	2011/09/27 10:14	52707	52276
123A3	2011/10/19 11:52	2011/09/27 10:14	52675	52253
123A4	2011/10/19 11:55	2011/09/27 10:14	52641	52222
123A5	2011/10/19 11:59	2011/09/27 10:14	52706	52283
123A6	2011/10/19 12:02	2011/09/27 10:14	52739	52385
123A7	2011/10/19 12:05	2011/09/27 10:14	52681	52349
123A8	2011/10/19 12:13	2011/09/27 10:14	52697	52435
123A9	2011/10/19 12:15	2011/09/27 10:14	52702	52388
123A10	2011/10/19 12:18	2011/09/27 10:14	52764	52437
123B1	2011/10/19 12:21	2011/09/27 10:14	52325	52657
123B2	2011/10/19 12:23	2011/09/27 10:14	52758	52647
123B3	2011/10/19 12:26	2011/09/27 10:14	52804	52709
123B4	2011/10/19 12:28	2011/09/27 10:14	52761	52751
123B5	2011/10/19 12:30	2011/09/27 10:14	52796	52747
123B6	2011/10/19 12:32	2011/09/27 10:14	52184	52776
123B7	2011/10/19 12:34	2011/09/27 10:14	52763	52354
123B8	2011/10/19 12:37	2011/09/27 10:14	52704	52411
123B9	2011/10/19 12:40	2011/09/27 10:14	52590	52351
123B10	2011/10/19 12:42	2011/09/27 10:14	52639	52476

Site	Timestamp		Specific Conductance (uS/cm)	
	IN	OUT	IN	OUT
122A1	2012/01/18 09:37	2012/01/18 09:39	50034	52463
122A2	2012/01/18 09:40	2012/01/18 09:41	52443	52475
122A3	2012/01/18 09:42	2012/01/18 09:43	52333	52472
122A4	2012/01/18 09:44	2012/01/18 09:45	52401	52404
122A5	2012/01/18 09:46	2012/01/18 09:47	51791	52475
122A6	2012/01/18 09:49	2012/01/18 09:50	52119	52480
122A7	2012/01/18 09:51	2012/01/18 09:51	51574	52485
122A8	2012/01/18 09:54	2012/01/18 09:55	51210	52439
122A9	2012/01/18 09:59	2012/01/18 10:00	52136	52483
122A10	2012/01/18 10:02	2012/01/18 10:03	51627	52461
122B1	2012/01/18 10:23	2012/01/18 10:25	52503	52503
122B2	2012/01/18 10:26	2012/01/18 10:27	52505	52494
122B3	2012/01/18 10:28	2012/01/18 10:30	52287	52503
122B4	2012/01/18 10:31	2012/01/18 10:32	52377	52489
122B5	2012/01/18 10:33	2012/01/18 10:35	52456	52501
122B6	2012/01/18 10:36	2012/01/18 10:38	52454	52502
122B7	2012/01/18 10:40	2012/01/18 10:41	52482	52509
122B8	2012/01/18 10:43	2012/01/18 10:44	52341	52509
122B9	2012/01/18 10:45	2012/01/18 10:47	52409	52511
122B10	2012/01/18 10:48	2012/01/18 10:49	52518	52507
123A1	2012/01/18 10:59	2012/01/18 11:00	52522	52512
123A2	2012/01/18 11:02	2012/01/18 11:03	52521	52511
123A3	2012/01/18 11:05	2012/01/18 11:07	52532	52504
123A4	2012/01/18 11:08	2012/01/18 11:09	52431	52500
123A5	2012/01/18 11:11	2012/01/18 11:12	52469	52507
123A6	2012/01/18 11:13	2012/01/18 11:15	52450	52513
123A7	2012/01/18 11:16	2012/01/18 11:17	52381	52507
123A8	2012/01/18 11:18	2012/01/18 11:20	52313	52500
123A9	2012/01/18 11:21	2012/01/18 11:22	52380	52507
123A10	2012/01/18 11:24	2012/01/18 11:25	52488	52504
123B1	2012/01/18 11:35	2012/01/18 11:36	52525	52520
123B2	2012/01/18 11:38	2012/01/18 11:39	52530	52512
123B3	2012/01/18 11:40	2012/01/18 11:41	52514	52510
123B4	2012/01/18 11:42	2012/01/18 11:43	52444	52510
123B5	2012/01/18 11:45	2012/01/18 11:46	52062	52527
123B6	2012/01/18 11:47	2012/01/18 11:49	52524	52526
123B7	2012/01/18 11:50	2012/01/18 11:51	52471	52516
123B8	2012/01/18 11:52	2012/01/18 11:53	52539	52511
123B9	2012/01/18 11:55	2012/01/18 11:56	52481	52521
123B10	2012/01/18 11:58	2012/01/18 11:59	52395	52516

Site	Timestamp		Specific Conductance (uS/cm)	
	IN	OUT	IN	OUT
122A1	2012/01/23 12:23	2012/01/23 12:25	52283	52494
122A2	2012/01/23 12:26	2012/01/23 12:28	50313	52459
122A3	2012/01/23 12:29	2012/01/23 12:31	52684	52527
122A4	2012/01/23 12:37	2012/01/23 12:39	52640	52572
122A5	2012/01/23 12:43	2012/01/23 12:46	52536	52365
122A6	2012/01/23 12:48	2012/01/23 12:49	52548	52541
122A7	2012/01/23 12:51	2012/01/23 12:52	52167	52627
122A8	2012/01/23 12:54	2012/01/23 12:55	52045	52539
122A9	2012/01/23 12:57	2012/01/23 12:59	52726	52595
122A10	2012/01/23 13:01	2012/01/23 13:02	52636	52513
122B1	2012/01/23 13:06	2012/01/23 13:07	52469	52691
122B2	2012/01/23 13:08	2012/01/23 13:10	52132	52632
122B3	2012/01/23 13:12	2012/01/23 13:13	52379	52607
122B4	2012/01/23 13:15	2012/01/23 13:16	52508	52630
122B5	2012/01/23 13:18	2012/01/23 13:19	52413	52643
122B6	2012/01/23 13:21	2012/01/23 13:22	50955	52595
122B7	2012/01/23 13:23	2012/01/23 13:25	51375	52631
122B8	2012/01/23 13:27	2012/01/23 13:28	52656	52681
122B9	2012/01/23 13:30	2012/01/23 13:31	52460	52661
122B10	2012/01/23 13:32	2012/01/23 13:34	52484	52650
123A1	2012/01/23 14:07	2012/01/23 14:08	51840	52739
123A2	2012/01/23 14:10	2012/01/23 14:12	52613	52733
123A3	2012/01/23 14:14	2012/01/23 14:15	52408	52738
123A4	2012/01/23 14:17	2012/01/23 14:23	52701	52710
123A5	2012/01/23 14:24	2012/01/23 14:26	52485	52736
123A6	2012/01/23 14:30	2012/01/23 14:32	52645	52742
123A7	2012/01/23 14:35	2012/01/23 14:37	52638	52745
123A8	2012/01/23 14:38	2012/01/23 14:40	52628	52733
123A9	2012/01/23 14:43	2012/01/23 14:44	52610	52736
123A10	2012/01/23 14:46	2012/01/23 14:47	52495	52729
123B1	2012/01/23 14:55	2012/01/23 14:56	52163	52748
123B2	2012/01/23 15:00	2012/01/23 15:02	52632	52654
123B3	2012/01/23 15:03	2012/01/23 15:05	52625	52758
123B4	2012/01/23 15:18	2012/01/23 16:11	52758	47.1
123B5	2012/01/23 16:13	2012/01/23 16:15	47.5	46.4
123B6	2012/01/23 16:17	2012/01/23 16:19	47.7	50.5
123B7	2012/01/23 16:21	2012/01/23 16:22	52462	56.6
123B8	2012/01/23 16:26	2012/01/23 16:27	52715	52712
123B9	2012/01/23 16:36	2012/01/23 16:38	46.8	47
123B10	2012/01/23 16:39	2012/01/23 16:40	47.1	46.8

Site	Timestamp		Specific Conductance (uS/cm)	
	IN	OUT	IN	OUT
122A1	2012/03/20 11:40	2012/03/20 14:21	53082	53501
122A2	2012/03/20 11:42	2012/03/20 14:22	53210	53539
122A3	2012/03/20 11:44	2012/03/20 14:24	53023	53528
122A4	2012/03/20 11:46	2012/03/20 14:26	53296	53527
122A5	2012/03/20 11:49	2012/03/20 14:27	53310	53514
122A6	2012/03/20 11:50	2012/03/20 14:28	53250	53517
122A7	2012/03/20 11:53	2012/03/20 14:30	53338	53517
122A8	2012/03/20 11:55	2012/03/20 14:31	52633	53524
122A9	2012/03/20 11:57	2012/03/20 14:31	53031	53529
122A10	2012/03/20 11:59	2012/03/20 14:32	53085	53524
122B1	2012/03/20 12:11	2012/03/20 15:08	52290	53644
122B2	2012/03/20 12:13	2012/03/20 15:09	53161	53523
122B3	2012/03/20 12:14	2012/03/20 15:10	53286	53528
122B4	2012/03/20 12:15	2012/03/20 15:11	52903	53521
122B5	2012/03/20 12:17	2012/03/20 15:12	51738	53514
122B6	2012/03/20 12:18	2012/03/20 15:13	53043	53512
122B7	2012/03/20 12:19	2012/03/20 15:13	53350	53525
122B8	2012/03/20 12:21	2012/03/20 15:14	52978	53545
122B9	2012/03/20 12:22	2012/03/20 15:15	52120	53531
122B10	2012/03/20 12:26	2012/03/20 15:16	53445	53516
123A1	2012/03/20 12:55	2012/03/20 14:37	52928	53522
123A2	2012/03/20 12:54	2012/03/20 14:38	52898	53648
123A3	2012/03/20 12:53	2012/03/20 14:39	53218	53529
123A4	2012/03/20 12:52	2012/03/20 14:41	53280	53521
123A5	2012/03/20 12:51	2012/03/20 14:42	52937	53519
123A6	2012/03/20 12:50	2012/03/20 14:43	53482	53515
123A7	2012/03/20 12:49	2012/03/20 14:44	53064	53536
123A8	2012/03/20 12:47	2012/03/20 14:46	53442	53535
123A9	2012/03/20 12:46	2012/03/20 14:47	52997	53508
123A10	2012/03/20 12:45	2012/03/20 14:48	53053	53527
123B1	2012/03/20 12:32	2012/03/20 14:51	53255	53549
123B2	2012/03/20 12:33	2012/03/20 14:52	52467	53528
123B3	2012/03/20 12:34	2012/03/20 14:53	53300	53524
123B4	2012/03/20 12:35	2012/03/20 14:54	53234	53656
123B5	2012/03/20 12:36	2012/03/20 14:54	52927	53539
123B6	2012/03/20 12:37	2012/03/20 14:55	53256	53531
123B7	2012/03/20 12:38	2012/03/20 14:56	52988	53530
123B8	2012/03/20 12:39	2012/03/20 14:57	53063	53532
123B9	2012/03/20 12:40	2012/03/20 14:57	53360	53528
123B10	2012/03/20 12:42	2012/03/20 14:58	53250	53529

Table C.1.2 (e)-(h) *– Abalone tank specific conductivity*

Site	Timestamp		Specific Conductance (uS/cm)	
	IN	OUT	IN	OUT
122A1	2012/03/27 10:42	2012/03/27 10:55	53005	53201
122A2	2012/03/27 10:43	2012/03/27 10:56	52720	53211
122A3	2012/03/27 10:44	2012/03/27 10:57	52948	53207
122A4	2012/03/27 10:45	2012/03/27 10:58	52995	53209
122A5	2012/03/27 10:47	2012/03/27 10:59	52853	53198
122A6	2012/03/27 10:48	2012/03/27 11:01	52984	53208
122A7	2012/03/27 10:49	2012/03/27 11:01	52618	53202
122A8	2012/03/27 10:50	2012/03/27 11:02	52858	53204
122A9	2012/03/27 10:52	2012/03/27 11:03	52765	53197
122A10	2012/03/27 10:53	2012/03/27 11:04	52874	53194
122B1	2012/03/27 11:06	2012/03/27 11:20	52297	53201
122B2	2012/03/27 11:08	2012/03/27 11:21	52546	53204
122B3	2012/03/27 11:09	2012/03/27 11:22	52492	53195
122B4	2012/03/27 11:11	2012/03/27 11:23	52546	53199
122B5	2012/03/27 11:12	2012/03/27 11:23	52554	53194
122B6	2012/03/27 11:13	2012/03/27 11:24	52841	53201
122B7	2012/03/27 11:14	2012/03/27 11:25	52985	53201
122B8	2012/03/27 11:15	2012/03/27 11:26	52659	53200
122B9	2012/03/27 11:16	2012/03/27 11:27	52920	53194
122B10	2012/03/27 11:17	2012/03/27 11:28	52791	53189
123A1	2012/03/27 11:44	2012/03/27 11:56	52527	53193
123A2	2012/03/27 11:45	2012/03/27 11:57	52947	53204
123A3	2012/03/27 11:47	2012/03/27 11:57	53137	53193
123A4	2012/03/27 11:48	2012/03/27 11:58	52817	53195
123A5	2012/03/27 11:49	2012/03/27 11:59	53100	53184
123A6	2012/03/27 11:50	2012/03/27 12:01	53069	53195
123A7	2012/03/27 11:51	2012/03/27 12:02	53118	53195
123A8	2012/03/27 11:52	2012/03/27 12:03	52794	53187
123A9	2012/03/27 11:53	2012/03/27 12:04	53065	53175
123A10	2012/03/27 11:54	2012/03/27 12:04	52856	53169
123B1	2012/03/27 14:15	2012/03/27 14:29	52872	53207
123B2	2012/03/27 14:16	2012/03/27 14:30	52363	53191
123B3	2012/03/27 14:19	2012/03/27 14:30	53059	53196
123B4	2012/03/27 14:20	2012/03/27 14:31	52994	53211
123B5	2012/03/27 14:21	2012/03/27 14:32	52882	53194
123B6	2012/03/27 14:22	2012/03/27 14:52	53071	53197
123B7	2012/03/27 14:23	2012/03/27 14:53	52894	53190
123B8	2012/03/27 14:24	2012/03/27 14:53	52954	53193
123B9	2012/03/27 14:25	2012/03/27 14:54	52953	53194
123B10	2012/03/27 14:26	2012/03/27 14:55	52829	53181

Site	Timestamp		Specific Conductance (uS/cm)	
	IN	OUT	IN	OUT
122A1	2012/04/03 11:12	2012/04/03 11:25	52544	53207
122A2	2012/04/03 11:13	2012/04/03 11:27	52646	53213
122A3	2012/04/03 11:14	2012/04/03 11:28	52962	53211
122A4	2012/04/03 11:15	2012/04/03 11:29	52521	53202
122A5	2012/04/03 11:16	2012/04/03 11:30	52420	53211
122A6	2012/04/03 11:17	2012/04/03 11:32	53051	53212
122A7	2012/04/03 11:18	2012/04/03 11:33	53108	53214
122A8	2012/04/03 11:20	2012/04/03 11:34	52395	53217
122A9	2012/04/03 11:21	2012/04/03 11:35	52770	53215
122A10	2012/04/03 11:22	2012/04/03 11:36	53110	53211
122B1	2012/04/03 12:08	2012/04/03 12:20	52486	53213
122B2	2012/04/03 12:09	2012/04/03 12:21	52704	53215
122B3	2012/04/03 12:11	2012/04/03 12:22	52484	53214
122B4	2012/04/03 12:13	2012/04/03 12:23	52857	53211
122B5	2012/04/03 12:13	2012/04/03 12:23	52747	53209
122B6	2012/04/03 12:14	2012/04/03 12:24	52821	53209
122B7	2012/04/03 12:15	2012/04/03 12:25	52976	53212
122B8	2012/04/03 12:16	2012/04/03 12:26	52657	53214
122B9	2012/04/03 12:17	2012/04/03 12:26	53000	53206
122B10	2012/04/03 12:18	2012/04/03 12:27	52847	53211
123A1	2012/04/03 14:49	2012/04/03 14:59	52536	53225
123A2	2012/04/03 14:50	2012/04/03 15:00	52466	53229
123A3	2012/04/03 14:51	2012/04/03 15:01	52732	53225
123A4	2012/04/03 14:52	2012/04/03 15:02	53074	53222
123A5	2012/04/03 14:53	2012/04/03 15:03	53155	53218
123A6	2012/04/03 14:54	2012/04/03 15:04	52893	53229
123A7	2012/04/03 14:55	2012/04/03 15:05	53082	53225
123A8	2012/04/03 14:56	2012/04/03 15:05	52605	53223
123A9	2012/04/03 14:57	2012/04/03 15:06	53098	53218
123A10	2012/04/03 14:57	2012/04/03 15:07	53052	53220
123B1	2012/04/03 15:27	2012/04/03 15:51	53023	53238
123B2	2012/04/03 15:28	2012/04/03 15:52	53041	53229
123B3	2012/04/03 15:29	2012/04/03 15:53	53092	53231
123B4	2012/04/03 15:30	2012/04/03 15:53	53062	53217
123B5	2012/04/03 15:31	2012/04/03 15:54	52780	53231
123B6	2012/04/03 15:32	2012/04/03 15:55	53085	53236
123B7	2012/04/03 15:33	2012/04/03 15:56	53105	53235
123B8	2012/04/03 15:34	2012/04/03 15:57	52610	53234
123B9	2012/04/03 15:35	2012/04/03 15:57	52796	53232
123B10	2012/04/03 15:36	2012/04/03 15:58	52362	53228

Site	Timestamp		Specific Conductance (uS/cm)	
	IN	OUT	IN	OUT
122A1	2012/04/19 10:52	2012/04/19 11:16	53050	53209
122A2	2012/04/19 10:53	2012/04/19 11:17	53013	53215
122A3	2012/04/19 10:54	2012/04/19 11:17	53103	53215
122A4	2012/04/19 10:55	2012/04/19 11:18	53122	53217
122A5	2012/04/19 10:56	2012/04/19 11:19	53046	53215
122A6	2012/04/19 10:57	2012/04/19 11:20	52802	53215
122A7	2012/04/19 10:58	2012/04/19 11:21	53119	53220
122A8	2012/04/19 11:00	2012/04/19 11:22	52980	53222
122A9	2012/04/19 11:01	2012/04/19 11:22	52974	53220
122A10	2012/04/19 11:02	2012/04/19 11:24	53193	53211
122B1	2012/04/19 11:04	2012/04/19 11:25	53152	53212
122B2	2012/04/19 11:05	2012/04/19 11:26	53211	53215
122B3	2012/04/19 11:06	2012/04/19 11:27	53124	53215
122B4	2012/04/19 11:07	2012/04/19 11:28	53160	53213
122B5	2012/04/19 11:08	2012/04/19 11:28	53160	53215
122B6	2012/04/19 11:09	2012/04/19 11:29	53004	53220
122B7	2012/04/19 11:10	2012/04/19 11:29	53052	53175
122B8	2012/04/19 11:11	2012/04/19 11:30	53154	53220
122B9	2012/04/19 11:12	2012/04/19 11:31	53063	53214
122B10	2012/04/19 11:13	2012/04/19 11:31	53152	53219
123A1	2012/04/19 11:41	2012/04/19 12:10	53180	53221
123A2	2012/04/19 11:41	2012/04/19 12:11	53143	53218
123A3	2012/04/19 11:42	2012/04/19 12:11	53103	53222
123A4	2012/04/19 11:43	2012/04/19 12:12	53069	53219
123A5	2012/04/19 11:44	2012/04/19 12:13	53094	53219
123A6	2012/04/19 11:45	2012/04/19 12:13	53187	53218
123A7	2012/04/19 11:46	2012/04/19 12:14	53022	53217
123A8	2012/04/19 11:47	2012/04/19 12:23	53162	53214
123A9	2012/04/19 11:48	2012/04/19 12:23	53024	53212
123A10	2012/04/19 11:49	2012/04/19 12:24	53117	53215
123B1	2012/04/19 11:53	2012/04/19 12:25	53198	53211
123B2	2012/04/19 11:54	2012/04/19 12:26	53130	53213
123B3	2012/04/19 11:55	2012/04/19 12:26	53095	53217
123B4	2012/04/19 11:56	2012/04/19 12:27	53147	53216
123B5	2012/04/19 11:57	2012/04/19 12:28	53175	53224
123B6	2012/04/19 11:58	2012/04/19 12:28	53153	53209
123B7	2012/04/19 11:59	2012/04/19 12:29	52899	53212
123B8	2012/04/19 11:59	2012/04/19 12:29	52955	53214
123B9	2012/04/19 12:00	2012/04/19 12:30	53134	53217
123B10	2012/04/19 12:01	2012/04/19 12:31	53165	53207

Site	Timestamp		Specific Conductance (uS/cm)	
	IN	OUT	IN	OUT
122A1	2012/04/26 11:00	2012/04/26 12:57	52983	53164
122A2	2012/04/26 11:01	2012/04/26 12:57	53147	53166
122A3	2012/04/26 11:02	2012/04/26 12:59	53119	53180
122A4	2012/04/26 11:04	2012/04/26 12:59	53173	53175
122A5	2012/04/26 11:05	2012/04/26 13:00	53100	53170
122A6	2012/04/26 11:06	2012/04/26 13:01	53163	53171
122A7	2012/04/26 11:07	2012/04/26 13:02	53099	53168
122A8	2012/04/26 11:08	2012/04/26 13:03	52958	53169
122A9	2012/04/26 11:10	2012/04/26 13:04	53146	53166
122A10	2012/04/26 11:11	2012/04/26 13:04	53149	53158
122B1	2012/04/26 11:25	2012/04/26 13:06	53127	53174
122B2	2012/04/26 11:26	2012/04/26 13:07	53178	53174
122B3	2012/04/26 11:28	2012/04/26 13:08	53117	53166
122B4	2012/04/26 11:29	2012/04/26 13:09	53152	53172
122B5	2012/04/26 11:31	2012/04/26 13:10	53171	53170
122B6	2012/04/26 11:32	2012/04/26 13:10	53142	53162
122B7	2012/04/26 11:33	2012/04/26 13:11	53064	53164
122B8	2012/04/26 11:34	2012/04/26 13:12	53161	53164
122B9	2012/04/26 11:35	2012/04/26 13:12	53005	53162
122B10	2012/04/26 11:36	2012/04/26 13:13	53107	53160
123A1	2012/04/26 11:41	2012/04/26 13:24	53010	53163
123A2	2012/04/26 11:42	2012/04/26 13:24	53156	53171
123A3	2012/04/26 11:43	2012/04/26 13:25	53083	53168
123A4	2012/04/26 11:44	2012/04/26 13:26	53133	53166
123A5	2012/04/26 11:46	2012/04/26 13:27	53170	53164
123A6	2012/04/26 11:47	2012/04/26 13:28	53170	53168
123A7	2012/04/26 11:48	2012/04/26 13:28	53031	53143
123A8	2012/04/26 11:49	2012/04/26 13:29	53130	53168
123A9	2012/04/26 11:50	2012/04/26 13:30	53034	53156
123A10	2012/04/26 11:51	2012/04/26 13:31	53144	53160
123B1	2012/04/26 11:54	2012/04/26 13:32	53181	53164
123B2	2012/04/26 11:55	2012/04/26 13:33	53136	53156
123B3	2012/04/26 11:56	2012/04/26 13:34	53163	53167
123B4	2012/04/26 11:57	2012/04/26 13:35	53169	53168
123B5	2012/04/26 11:59	2012/04/26 13:35	53164	53158
123B6	2012/04/26 12:00	2012/04/26 13:37	53141	53160
123B7	2012/04/26 12:01	2012/04/26 13:37	53112	53156
123B8	2012/04/26 12:02	2012/04/26 13:38	53134	53151
123B9	2012/04/26 12:02	2012/04/26 13:39	53054	53154
123B10	2012/04/26 12:03	2012/04/26 13:39	53131	53136

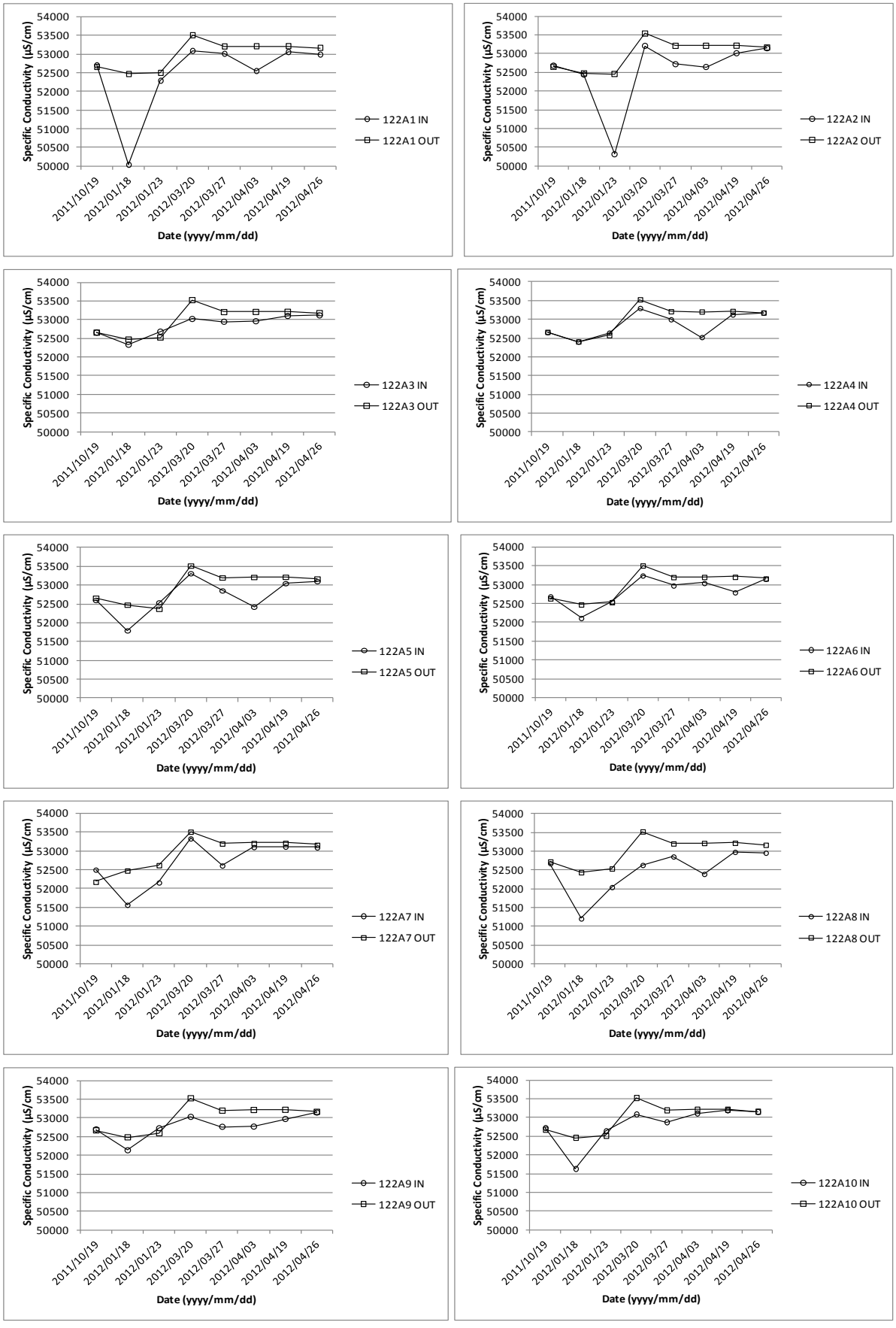


Figure C.1.2.1 *– Row 122A abalone tank specific conductivity*

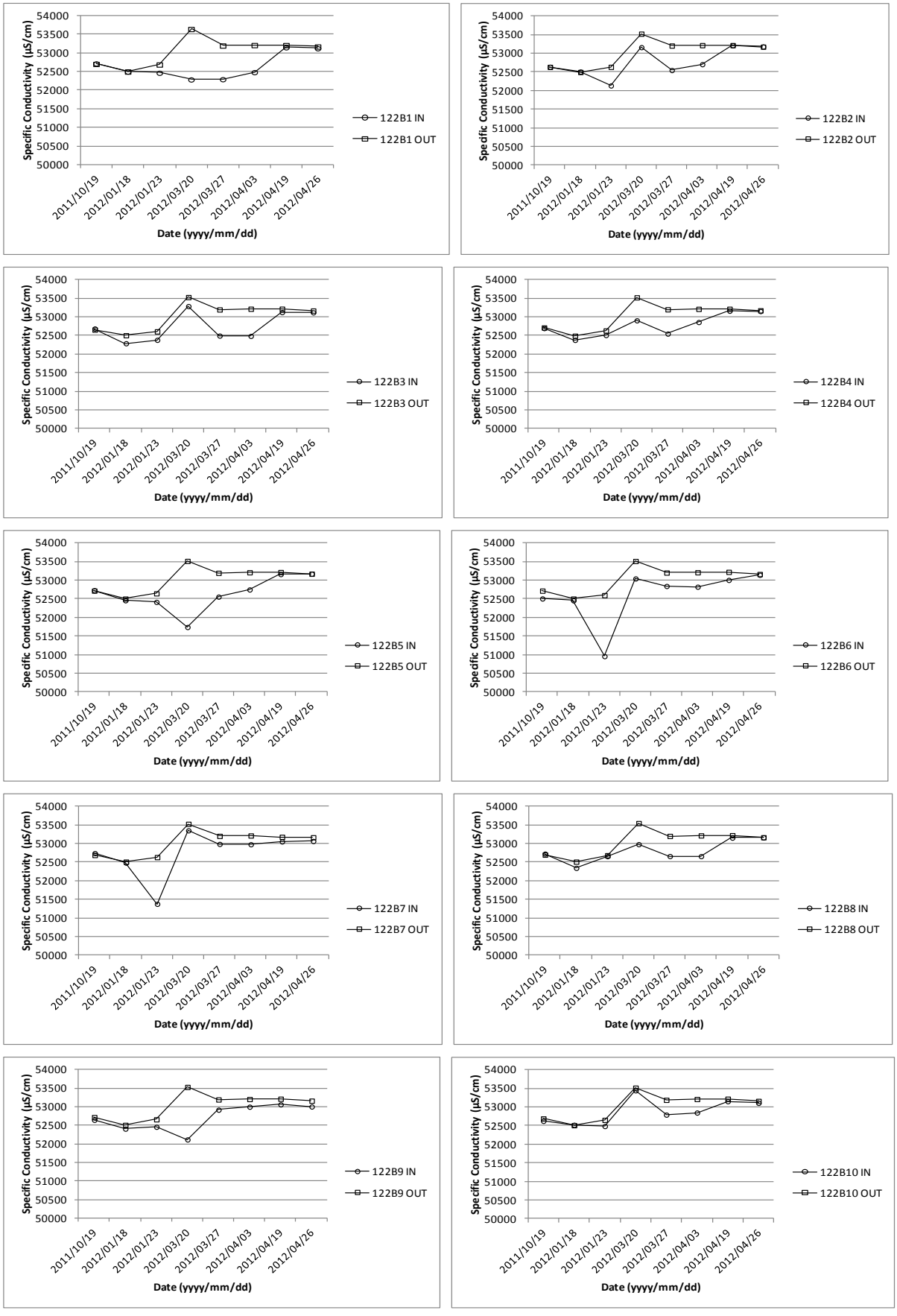


Figure C.1.2.2 *– Row 122B abalone tank specific conductivity*

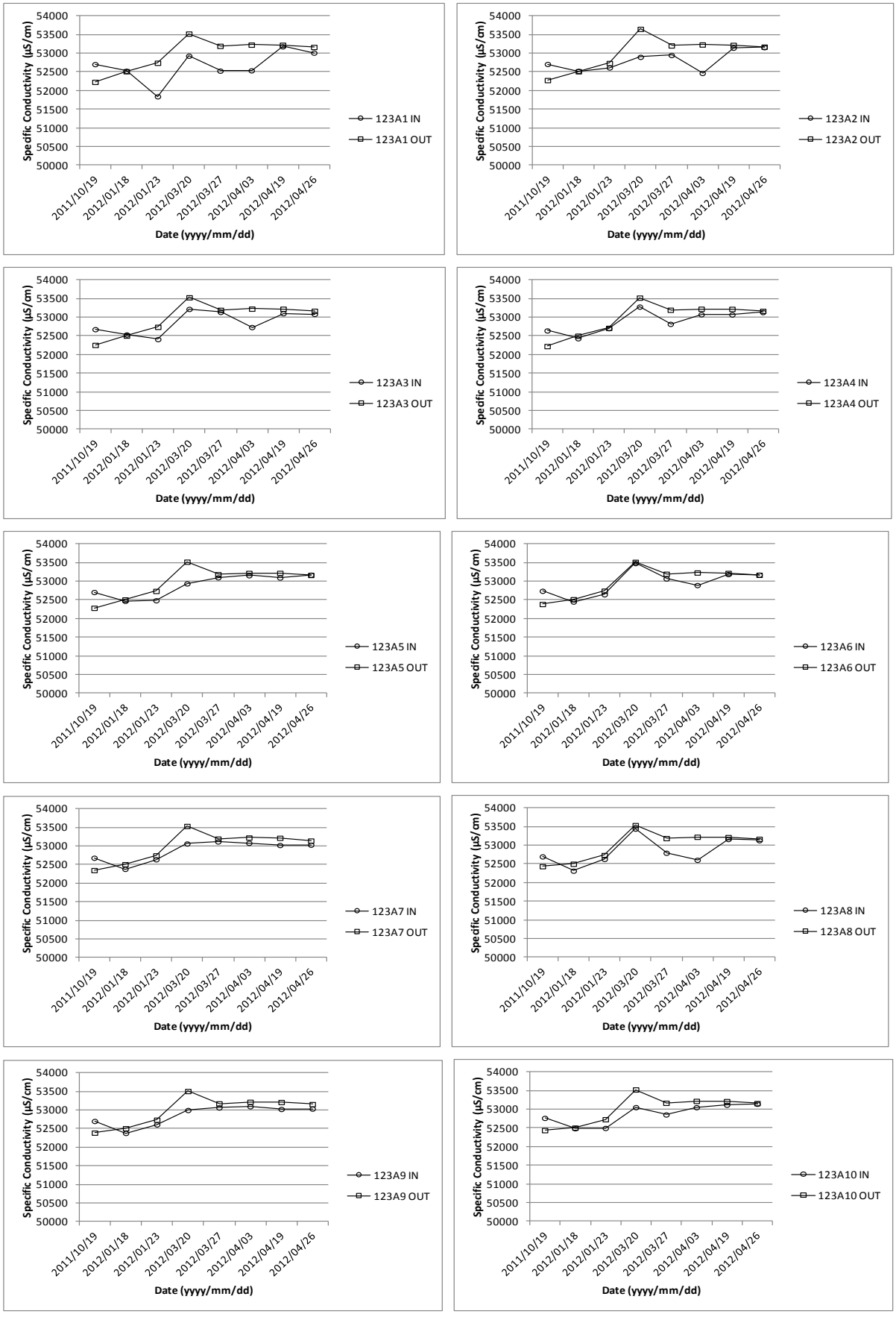


Figure C.1.2.3 *– Row 123A abalone tank specific conductivity*

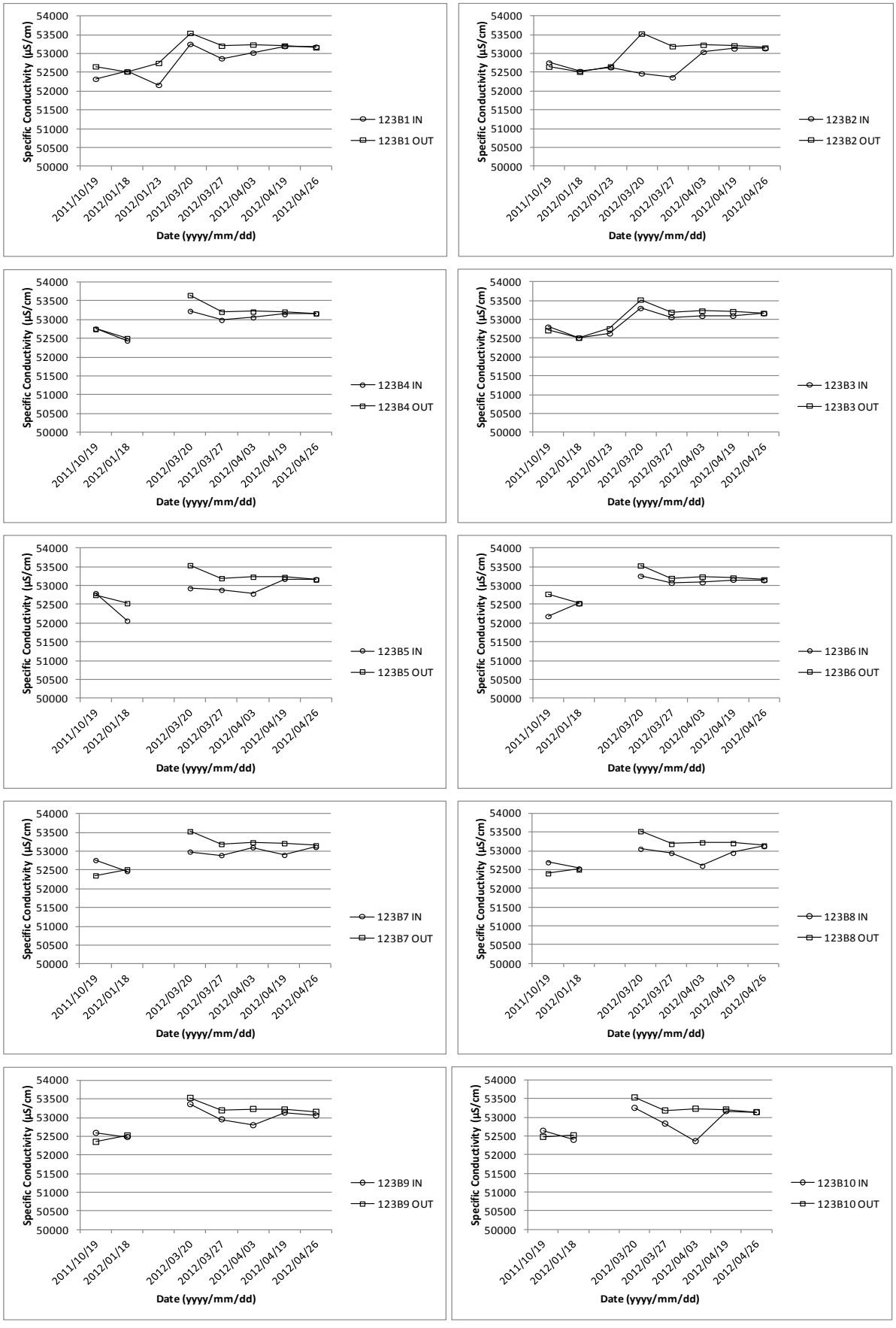


Figure C.1.2.4 *– Row 123B abalone tank specific conductivity*

C.1.3 Total Dissolved Solids (TDS)

Table C.1.3 (a)-(d) *– Abalone tank TDS*

Site	Timestamp		TDS (g/L)	
	IN	OUT	IN	OUT
122A1	2011/10/19 09:26	2011/09/27 10:14	34.255	34.2225
122A2	2011/10/19 09:29	2011/09/27 10:14	34.242	34.2225
122A3	2011/10/19 09:32	2011/09/27 10:14	34.229	34.229
122A4	2011/10/19 09:35	2011/09/27 10:14	34.2225	34.229
122A5	2011/10/19 09:38	2011/09/27 10:14	34.19	34.229
122A6	2011/10/19 09:41	2011/09/27 10:14	34.255	34.216
122A7	2011/10/19 09:45	2011/09/27 10:14	34.1315	33.9235
122A8	2011/10/19 09:48	2011/09/27 10:14	34.242	34.2745
122A9	2011/10/19 09:52	2011/09/27 10:14	34.255	34.2355
122A10	2011/10/19 09:55	2011/09/27 10:14	34.268	34.242
122B1	2011/10/19 10:02	2011/09/27 10:14	34.268	34.2615
122B2	2011/10/19 10:04	2011/09/27 10:14	34.2095	34.2095
122B3	2011/10/19 10:08	2011/09/27 10:14	34.242	34.2225
122B4	2011/10/19 10:11	2011/09/27 10:14	34.2485	34.2615
122B5	2011/10/19 10:15	2011/09/27 10:14	34.2745	34.268
122B6	2011/10/19 10:20	2011/09/27 10:14	34.125	34.268
122B7	2011/10/19 10:23	2011/09/27 10:14	34.281	34.2485
122B8	2011/10/19 10:26	2011/09/27 10:14	34.268	34.255
122B9	2011/10/19 10:30	2011/09/27 10:14	34.2225	34.268
122B10	2011/10/19 10:32	2011/09/27 10:14	34.203	34.2485
123A1	2011/10/19 11:45	2011/09/27 10:14	34.255	33.9495
123A2	2011/10/19 11:48	2011/09/27 10:14	34.2615	33.982
123A3	2011/10/19 11:52	2011/09/27 10:14	34.2355	33.9625
123A4	2011/10/19 11:55	2011/09/27 10:14	34.216	33.943
123A5	2011/10/19 11:59	2011/09/27 10:14	34.2615	33.982
123A6	2011/10/19 12:02	2011/09/27 10:14	34.281	34.0535
123A7	2011/10/19 12:05	2011/09/27 10:14	34.242	34.0275
123A8	2011/10/19 12:13	2011/09/27 10:14	34.255	34.086
123A9	2011/10/19 12:15	2011/09/27 10:14	34.255	34.0535
123A10	2011/10/19 12:18	2011/09/27 10:14	34.294	34.086
123B1	2011/10/19 12:21	2011/09/27 10:14	34.008	34.229
123B2	2011/10/19 12:23	2011/09/27 10:14	34.294	34.2225
123B3	2011/10/19 12:26	2011/09/27 10:14	34.32	34.2615
123B4	2011/10/19 12:28	2011/09/27 10:14	34.294	34.2875
123B5	2011/10/19 12:30	2011/09/27 10:14	34.32	34.2875
123B6	2011/10/19 12:32	2011/09/27 10:14	33.917	34.307
123B7	2011/10/19 12:34	2011/09/27 10:14	34.294	34.0275
123B8	2011/10/19 12:37	2011/09/27 10:14	34.255	34.0665
123B9	2011/10/19 12:40	2011/09/27 10:14	34.1835	34.0275
123B10	2011/10/19 12:42	2011/09/27 10:14	34.216	34.112

Site	Timestamp		TDS (g/L)	
	IN	OUT	IN	OUT
122A1	2012/01/18 09:37	2012/01/18 09:39	32.5195	34.099
122A2	2012/01/18 09:40	2012/01/18 09:41	34.086	34.1055
122A3	2012/01/18 09:42	2012/01/18 09:43	34.0145	34.1055
122A4	2012/01/18 09:44	2012/01/18 09:45	34.06	34.06
122A5	2012/01/18 09:46	2012/01/18 09:47	33.6635	34.112
122A6	2012/01/18 09:49	2012/01/18 09:50	33.878	34.112
122A7	2012/01/18 09:51	2012/01/18 09:51	33.5205	34.112
122A8	2012/01/18 09:54	2012/01/18 09:55	33.2865	34.086
122A9	2012/01/18 09:59	2012/01/18 10:00	33.891	34.112
122A10	2012/01/18 10:02	2012/01/18 10:03	33.5595	34.099
122B1	2012/01/18 10:23	2012/01/18 10:25	34.125	34.125
122B2	2012/01/18 10:26	2012/01/18 10:27	34.125	34.1185
122B3	2012/01/18 10:28	2012/01/18 10:30	33.9885	34.125
122B4	2012/01/18 10:31	2012/01/18 10:32	34.047	34.1185
122B5	2012/01/18 10:33	2012/01/18 10:35	34.099	34.125
122B6	2012/01/18 10:36	2012/01/18 10:38	34.0925	34.125
122B7	2012/01/18 10:40	2012/01/18 10:41	34.112	34.1315
122B8	2012/01/18 10:43	2012/01/18 10:44	34.021	34.1315
122B9	2012/01/18 10:45	2012/01/18 10:47	34.0665	34.1315
122B10	2012/01/18 10:48	2012/01/18 10:49	34.138	34.1315
123A1	2012/01/18 10:59	2012/01/18 11:00	34.138	34.1315
123A2	2012/01/18 11:02	2012/01/18 11:03	34.138	34.1315
123A3	2012/01/18 11:05	2012/01/18 11:07	34.1445	34.125
123A4	2012/01/18 11:08	2012/01/18 11:09	34.0795	34.125
123A5	2012/01/18 11:11	2012/01/18 11:12	34.1055	34.1315
123A6	2012/01/18 11:13	2012/01/18 11:15	34.0925	34.1315
123A7	2012/01/18 11:16	2012/01/18 11:17	34.047	34.1315
123A8	2012/01/18 11:18	2012/01/18 11:20	34.0015	34.125
123A9	2012/01/18 11:21	2012/01/18 11:22	34.047	34.1315
123A10	2012/01/18 11:24	2012/01/18 11:25	34.1185	34.125
123B1	2012/01/18 11:35	2012/01/18 11:36	34.1445	34.138
123B2	2012/01/18 11:38	2012/01/18 11:39	34.1445	34.1315
123B3	2012/01/18 11:40	2012/01/18 11:41	34.1315	34.1315
123B4	2012/01/18 11:42	2012/01/18 11:43	34.086	34.1315
123B5	2012/01/18 11:45	2012/01/18 11:46	33.839	34.1445
123B6	2012/01/18 11:47	2012/01/18 11:49	34.138	34.1445
123B7	2012/01/18 11:50	2012/01/18 11:51	34.1055	34.138
123B8	2012/01/18 11:52	2012/01/18 11:53	34.151	34.1315
123B9	2012/01/18 11:55	2012/01/18 11:56	34.112	34.138
123B10	2012/01/18 11:58	2012/01/18 11:59	34.0535	34.138

Site	Timestamp		TDS (g/L)	
	IN	OUT	IN	OUT
122A1	2012/01/23 12:23	2012/01/23 12:25	33.982	34.1185
122A2	2012/01/23 12:26	2012/01/23 12:28	32.7015	34.099
122A3	2012/01/23 12:29	2012/01/23 12:31	34.242	34.1445
122A4	2012/01/23 12:37	2012/01/23 12:39	34.216	34.1705
122A5	2012/01/23 12:43	2012/01/23 12:46	34.151	34.034
122A6	2012/01/23 12:48	2012/01/23 12:49	34.1575	34.151
122A7	2012/01/23 12:51	2012/01/23 12:52	33.9105	34.2095
122A8	2012/01/23 12:54	2012/01/23 12:55	33.8325	34.151
122A9	2012/01/23 12:57	2012/01/23 12:59	34.2745	34.1835
122A10	2012/01/23 13:01	2012/01/23 13:02	34.216	34.1315
122B1	2012/01/23 13:06	2012/01/23 13:07	34.1055	34.2485
122B2	2012/01/23 13:08	2012/01/23 13:10	33.8845	34.2095
122B3	2012/01/23 13:12	2012/01/23 13:13	34.047	34.1965
122B4	2012/01/23 13:15	2012/01/23 13:16	34.1315	34.2095
122B5	2012/01/23 13:18	2012/01/23 13:19	34.0665	34.216
122B6	2012/01/23 13:21	2012/01/23 13:22	33.1175	34.19
122B7	2012/01/23 13:23	2012/01/23 13:25	33.397	34.2095
122B8	2012/01/23 13:27	2012/01/23 13:28	34.229	34.242
122B9	2012/01/23 13:30	2012/01/23 13:31	34.099	34.229
122B10	2012/01/23 13:32	2012/01/23 13:34	34.112	34.2225
123A1	2012/01/23 14:07	2012/01/23 14:08	33.696	34.281
123A2	2012/01/23 14:10	2012/01/23 14:12	34.1965	34.2745
123A3	2012/01/23 14:14	2012/01/23 14:15	34.0665	34.281
123A4	2012/01/23 14:17	2012/01/23 14:23	34.255	34.2615
123A5	2012/01/23 14:24	2012/01/23 14:26	34.1185	34.281
123A6	2012/01/23 14:30	2012/01/23 14:32	34.216	34.281
123A7	2012/01/23 14:35	2012/01/23 14:37	34.216	34.2875
123A8	2012/01/23 14:38	2012/01/23 14:40	34.2095	34.2745
123A9	2012/01/23 14:43	2012/01/23 14:44	34.1965	34.281
123A10	2012/01/23 14:46	2012/01/23 14:47	34.125	34.2745
123B1	2012/01/23 14:55	2012/01/23 14:56	33.904	34.2875
123B2	2012/01/23 15:00	2012/01/23 15:02	34.2095	34.2225
123B3	2012/01/23 15:03	2012/01/23 15:05	34.203	34.294
123B4	2012/01/23 15:18	2012/01/23 16:11	34.294	0.0305
123B5	2012/01/23 16:13	2012/01/23 16:15	0.0312	0.0299
123B6	2012/01/23 16:17	2012/01/23 16:19	0.0312	0.0325
123B7	2012/01/23 16:21	2012/01/23 16:22	34.099	0.037
123B8	2012/01/23 16:26	2012/01/23 16:27	34.268	34.2615
123B9	2012/01/23 16:36	2012/01/23 16:38	0.0305	0.0305
123B10	2012/01/23 16:39	2012/01/23 16:40	0.0305	0.0305

Site	Timestamp		TDS (g/L)	
	IN	OUT	IN	OUT
122A1	2012/03/20 11:40	2012/03/20 14:21	34.50	34.775
122A2	2012/03/20 11:42	2012/03/20 14:22	34.59	34.801
122A3	2012/03/20 11:44	2012/03/20 14:24	34.46	34.7945
122A4	2012/03/20 11:46	2012/03/20 14:26	34.65	34.7945
122A5	2012/03/20 11:49	2012/03/20 14:27	34.65	34.7815
122A6	2012/03/20 11:50	2012/03/20 14:28	34.61	34.788
122A7	2012/03/20 11:53	2012/03/20 14:30	34.67	34.788
122A8	2012/03/20 11:55	2012/03/20 14:31	34.21	34.788
122A9	2012/03/20 11:57	2012/03/20 14:31	34.47	34.7945
122A10	2012/03/20 11:59	2012/03/20 14:32	34.51	34.788
122B1	2012/03/20 12:11	2012/03/20 15:08	33.99	34.866
122B2	2012/03/20 12:13	2012/03/20 15:09	34.55	34.788
122B3	2012/03/20 12:14	2012/03/20 15:10	34.64	34.7945
122B4	2012/03/20 12:15	2012/03/20 15:11	34.39	34.788
122B5	2012/03/20 12:17	2012/03/20 15:12	33.63	34.7815
122B6	2012/03/20 12:18	2012/03/20 15:13	34.48	34.7815
122B7	2012/03/20 12:19	2012/03/20 15:13	34.68	34.788
122B8	2012/03/20 12:21	2012/03/20 15:14	34.44	34.8075
122B9	2012/03/20 12:22	2012/03/20 15:15	33.88	34.7945
122B10	2012/03/20 12:26	2012/03/20 15:16	34.74	34.788
123A1	2012/03/20 12:55	2012/03/20 14:37	34.40	34.788
123A2	2012/03/20 12:54	2012/03/20 14:38	34.39	34.8725
123A3	2012/03/20 12:53	2012/03/20 14:39	34.59	34.7945
123A4	2012/03/20 12:52	2012/03/20 14:41	34.63	34.788
123A5	2012/03/20 12:51	2012/03/20 14:42	34.41	34.788
123A6	2012/03/20 12:50	2012/03/20 14:43	34.76	34.788
123A7	2012/03/20 12:49	2012/03/20 14:44	34.49	34.801
123A8	2012/03/20 12:47	2012/03/20 14:46	34.74	34.7945
123A9	2012/03/20 12:46	2012/03/20 14:47	34.45	34.7815
123A10	2012/03/20 12:45	2012/03/20 14:48	34.48	34.7945
123B1	2012/03/20 12:32	2012/03/20 14:51	34.62	34.8075
123B2	2012/03/20 12:33	2012/03/20 14:52	34.11	34.7945
123B3	2012/03/20 12:34	2012/03/20 14:53	34.65	34.788
123B4	2012/03/20 12:35	2012/03/20 14:54	34.60	34.879
123B5	2012/03/20 12:36	2012/03/20 14:54	34.40	34.801
123B6	2012/03/20 12:37	2012/03/20 14:55	34.62	34.7945
123B7	2012/03/20 12:38	2012/03/20 14:56	34.44	34.7945
123B8	2012/03/20 12:39	2012/03/20 14:57	34.49	34.7945
123B9	2012/03/20 12:40	2012/03/20 14:57	34.68	34.7945
123B10	2012/03/20 12:42	2012/03/20 14:58	34.61	34.7945

Table C.1.3 (e)-(h) *– Abalone tank TDS*

Site	Timestamp		TDS (g/L)	
	IN	OUT	IN	OUT
122A1	2012/03/27 10:42	2012/03/27 10:55	34.46	34.58
122A2	2012/03/27 10:43	2012/03/27 10:56	34.27	34.5865
122A3	2012/03/27 10:44	2012/03/27 10:57	34.42	34.5865
122A4	2012/03/27 10:45	2012/03/27 10:58	34.45	34.5865
122A5	2012/03/27 10:47	2012/03/27 10:59	34.35	34.58
122A6	2012/03/27 10:48	2012/03/27 11:01	34.44	34.5865
122A7	2012/03/27 10:49	2012/03/27 11:01	34.20	34.58
122A8	2012/03/27 10:50	2012/03/27 11:02	34.36	34.58
122A9	2012/03/27 10:52	2012/03/27 11:03	34.30	34.58
122A10	2012/03/27 10:53	2012/03/27 11:04	34.37	34.5735
122B1	2012/03/27 11:06	2012/03/27 11:20	34.00	34.58
122B2	2012/03/27 11:08	2012/03/27 11:21	34.16	34.58
122B3	2012/03/27 11:09	2012/03/27 11:22	34.12	34.58
122B4	2012/03/27 11:11	2012/03/27 11:23	34.16	34.58
122B5	2012/03/27 11:12	2012/03/27 11:23	34.16	34.5735
122B6	2012/03/27 11:13	2012/03/27 11:24	34.35	34.58
122B7	2012/03/27 11:14	2012/03/27 11:25	34.44	34.58
122B8	2012/03/27 11:15	2012/03/27 11:26	34.23	34.58
122B9	2012/03/27 11:16	2012/03/27 11:27	34.40	34.5735
122B10	2012/03/27 11:17	2012/03/27 11:28	34.31	34.5735
123A1	2012/03/27 11:44	2012/03/27 11:56	34.14	34.5735
123A2	2012/03/27 11:45	2012/03/27 11:57	34.42	34.58
123A3	2012/03/27 11:47	2012/03/27 11:57	34.54	34.5735
123A4	2012/03/27 11:48	2012/03/27 11:58	34.33	34.5735
123A5	2012/03/27 11:49	2012/03/27 11:59	34.52	34.567
123A6	2012/03/27 11:50	2012/03/27 12:01	34.50	34.5735
123A7	2012/03/27 11:51	2012/03/27 12:02	34.53	34.5735
123A8	2012/03/27 11:52	2012/03/27 12:03	34.31	34.5735
123A9	2012/03/27 11:53	2012/03/27 12:04	34.50	34.5605
123A10	2012/03/27 11:54	2012/03/27 12:04	34.36	34.5605
123B1	2012/03/27 14:15	2012/03/27 14:29	34.37	34.5865
123B2	2012/03/27 14:16	2012/03/27 14:30	34.03	34.5735
123B3	2012/03/27 14:19	2012/03/27 14:30	34.49	34.58
123B4	2012/03/27 14:20	2012/03/27 14:31	34.44	34.5865
123B5	2012/03/27 14:21	2012/03/27 14:32	34.37	34.5735
123B6	2012/03/27 14:22	2012/03/27 14:52	34.50	34.58
123B7	2012/03/27 14:23	2012/03/27 14:53	34.38	34.5735
123B8	2012/03/27 14:24	2012/03/27 14:53	34.42	34.5735
123B9	2012/03/27 14:25	2012/03/27 14:54	34.42	34.5735
123B10	2012/03/27 14:26	2012/03/27 14:55	34.34	34.567

Site	Timestamp		TDS (g/L)	
	IN	OUT	IN	OUT
122A1	2012/04/03 11:12	2012/04/03 11:25	34.15	34.5865
122A2	2012/04/03 11:13	2012/04/03 11:27	34.22	34.5865
122A3	2012/04/03 11:14	2012/04/03 11:28	34.42	34.5865
122A4	2012/04/03 11:15	2012/04/03 11:29	34.14	34.58
122A5	2012/04/03 11:16	2012/04/03 11:30	34.07	34.5865
122A6	2012/04/03 11:17	2012/04/03 11:32	34.48	34.5865
122A7	2012/04/03 11:18	2012/04/03 11:33	34.52	34.5865
122A8	2012/04/03 11:20	2012/04/03 11:34	34.05	34.593
122A9	2012/04/03 11:21	2012/04/03 11:35	34.30	34.593
122A10	2012/04/03 11:22	2012/04/03 11:36	34.52	34.5865
122B1	2012/04/03 12:08	2012/04/03 12:20	34.12	34.5865
122B2	2012/04/03 12:09	2012/04/03 12:21	34.26	34.593
122B3	2012/04/03 12:11	2012/04/03 12:22	34.11	34.5865
122B4	2012/04/03 12:13	2012/04/03 12:23	34.36	34.5865
122B5	2012/04/03 12:13	2012/04/03 12:23	34.29	34.5865
122B6	2012/04/03 12:14	2012/04/03 12:24	34.33	34.5865
122B7	2012/04/03 12:15	2012/04/03 12:25	34.44	34.5865
122B8	2012/04/03 12:16	2012/04/03 12:26	34.23	34.5865
122B9	2012/04/03 12:17	2012/04/03 12:26	34.45	34.5865
122B10	2012/04/03 12:18	2012/04/03 12:27	34.35	34.5865
123A1	2012/04/03 14:49	2012/04/03 14:59	34.15	34.5995
123A2	2012/04/03 14:50	2012/04/03 15:00	34.11	34.5995
123A3	2012/04/03 14:51	2012/04/03 15:01	34.27	34.593
123A4	2012/04/03 14:52	2012/04/03 15:02	34.50	34.593
123A5	2012/04/03 14:53	2012/04/03 15:03	34.55	34.593
123A6	2012/04/03 14:54	2012/04/03 15:04	34.38	34.5995
123A7	2012/04/03 14:55	2012/04/03 15:05	34.50	34.593
123A8	2012/04/03 14:56	2012/04/03 15:05	34.20	34.593
123A9	2012/04/03 14:57	2012/04/03 15:06	34.52	34.593
123A10	2012/04/03 14:57	2012/04/03 15:07	34.48	34.593
123B1	2012/04/03 15:27	2012/04/03 15:51	34.46	34.606
123B2	2012/04/03 15:28	2012/04/03 15:52	34.48	34.5995
123B3	2012/04/03 15:29	2012/04/03 15:53	34.51	34.5995
123B4	2012/04/03 15:30	2012/04/03 15:53	34.49	34.593
123B5	2012/04/03 15:31	2012/04/03 15:54	34.31	34.5995
123B6	2012/04/03 15:32	2012/04/03 15:55	34.51	34.606
123B7	2012/04/03 15:33	2012/04/03 15:56	34.52	34.5995
123B8	2012/04/03 15:34	2012/04/03 15:57	34.20	34.5995
123B9	2012/04/03 15:35	2012/04/03 15:57	34.32	34.5995
123B10	2012/04/03 15:36	2012/04/03 15:58	34.03	34.5995

Site	Timestamp		TDS (g/L)	
	IN	OUT	IN	OUT
122A1	2012/04/19 10:52	2012/04/19 11:16	34.48	34.5865
122A2	2012/04/19 10:53	2012/04/19 11:17	34.46	34.5865
122A3	2012/04/19 10:54	2012/04/19 11:17	34.52	34.593
122A4	2012/04/19 10:55	2012/04/19 11:18	34.53	34.593
122A5	2012/04/19 10:56	2012/04/19 11:19	34.48	34.593
122A6	2012/04/19 10:57	2012/04/19 11:20	34.32	34.5865
122A7	2012/04/19 10:58	2012/04/19 11:21	34.53	34.593
122A8	2012/04/19 11:00	2012/04/19 11:22	34.44	34.593
122A9	2012/04/19 11:01	2012/04/19 11:22	34.43	34.593
122A10	2012/04/19 11:02	2012/04/19 11:24	34.57	34.5865
122B1	2012/04/19 11:04	2012/04/19 11:25	34.55	34.5865
122B2	2012/04/19 11:05	2012/04/19 11:26	34.59	34.5865
122B3	2012/04/19 11:06	2012/04/19 11:27	34.53	34.593
122B4	2012/04/19 11:07	2012/04/19 11:28	34.55	34.5865
122B5	2012/04/19 11:08	2012/04/19 11:28	34.55	34.593
122B6	2012/04/19 11:09	2012/04/19 11:29	34.45	34.593
122B7	2012/04/19 11:10	2012/04/19 11:29	34.48	34.567
122B8	2012/04/19 11:11	2012/04/19 11:30	34.55	34.593
122B9	2012/04/19 11:12	2012/04/19 11:31	34.49	34.5865
122B10	2012/04/19 11:13	2012/04/19 11:31	34.55	34.593
123A1	2012/04/19 11:41	2012/04/19 12:10	34.57	34.593
123A2	2012/04/19 11:41	2012/04/19 12:11	34.54	34.593
123A3	2012/04/19 11:42	2012/04/19 12:11	34.52	34.593
123A4	2012/04/19 11:43	2012/04/19 12:12	34.50	34.593
123A5	2012/04/19 11:44	2012/04/19 12:13	34.51	34.593
123A6	2012/04/19 11:45	2012/04/19 12:13	34.57	34.593
123A7	2012/04/19 11:46	2012/04/19 12:14	34.46	34.593
123A8	2012/04/19 11:47	2012/04/19 12:23	34.55	34.5865
123A9	2012/04/19 11:48	2012/04/19 12:23	34.46	34.5865
123A10	2012/04/19 11:49	2012/04/19 12:24	34.53	34.5865
123B1	2012/04/19 11:53	2012/04/19 12:25	34.58	34.5865
123B2	2012/04/19 11:54	2012/04/19 12:26	34.53	34.5865
123B3	2012/04/19 11:55	2012/04/19 12:26	34.52	34.593
123B4	2012/04/19 11:56	2012/04/19 12:27	34.55	34.593
123B5	2012/04/19 11:57	2012/04/19 12:28	34.56	34.593
123B6	2012/04/19 11:58	2012/04/19 12:28	34.55	34.5865
123B7	2012/04/19 11:59	2012/04/19 12:29	34.39	34.5865
123B8	2012/04/19 11:59	2012/04/19 12:29	34.42	34.5865
123B9	2012/04/19 12:00	2012/04/19 12:30	34.53	34.593
123B10	2012/04/19 12:01	2012/04/19 12:31	34.55	34.5865

Site	Timestamp		TDS (g/L)	
	IN	OUT	IN	OUT
122A1	2012/04/26 11:00	2012/04/26 12:57	34.44	34.55
122A2	2012/04/26 11:01	2012/04/26 12:57	34.55	34.56
122A3	2012/04/26 11:02	2012/04/26 12:59	34.53	34.57
122A4	2012/04/26 11:04	2012/04/26 12:59	34.56	34.56
122A5	2012/04/26 11:05	2012/04/26 13:00	34.52	34.56
122A6	2012/04/26 11:06	2012/04/26 13:01	34.55	34.56
122A7	2012/04/26 11:07	2012/04/26 13:02	34.52	34.56
122A8	2012/04/26 11:08	2012/04/26 13:03	34.42	34.56
122A9	2012/04/26 11:10	2012/04/26 13:04	34.55	34.56
122A10	2012/04/26 11:11	2012/04/26 13:04	34.55	34.55
122B1	2012/04/26 11:25	2012/04/26 13:06	34.53	34.56
122B2	2012/04/26 11:26	2012/04/26 13:07	34.57	34.56
122B3	2012/04/26 11:28	2012/04/26 13:08	34.53	34.56
122B4	2012/04/26 11:29	2012/04/26 13:09	34.55	34.56
122B5	2012/04/26 11:31	2012/04/26 13:10	34.56	34.56
122B6	2012/04/26 11:32	2012/04/26 13:10	34.54	34.55
122B7	2012/04/26 11:33	2012/04/26 13:11	34.49	34.55
122B8	2012/04/26 11:34	2012/04/26 13:12	34.55	34.55
122B9	2012/04/26 11:35	2012/04/26 13:12	34.46	34.55
122B10	2012/04/26 11:36	2012/04/26 13:13	34.52	34.55
123A1	2012/04/26 11:41	2012/04/26 13:24	34.46	34.55
123A2	2012/04/26 11:42	2012/04/26 13:24	34.55	34.56
123A3	2012/04/26 11:43	2012/04/26 13:25	34.50	34.56
123A4	2012/04/26 11:44	2012/04/26 13:26	34.53	34.56
123A5	2012/04/26 11:46	2012/04/26 13:27	34.56	34.55
123A6	2012/04/26 11:47	2012/04/26 13:28	34.56	34.56
123A7	2012/04/26 11:48	2012/04/26 13:28	34.47	34.54
123A8	2012/04/26 11:49	2012/04/26 13:29	34.53	34.56
123A9	2012/04/26 11:50	2012/04/26 13:30	34.47	34.55
123A10	2012/04/26 11:51	2012/04/26 13:31	34.54	34.55
123B1	2012/04/26 11:54	2012/04/26 13:32	34.57	34.55
123B2	2012/04/26 11:55	2012/04/26 13:33	34.54	34.55
123B3	2012/04/26 11:56	2012/04/26 13:34	34.55	34.56
123B4	2012/04/26 11:57	2012/04/26 13:35	34.56	34.56
123B5	2012/04/26 11:59	2012/04/26 13:35	34.55	34.55
123B6	2012/04/26 12:00	2012/04/26 13:37	34.54	34.55
123B7	2012/04/26 12:01	2012/04/26 13:37	34.52	34.55
123B8	2012/04/26 12:02	2012/04/26 13:38	34.53	34.55
123B9	2012/04/26 12:02	2012/04/26 13:39	34.48	34.55
123B10	2012/04/26 12:03	2012/04/26 13:39	34.53	34.54

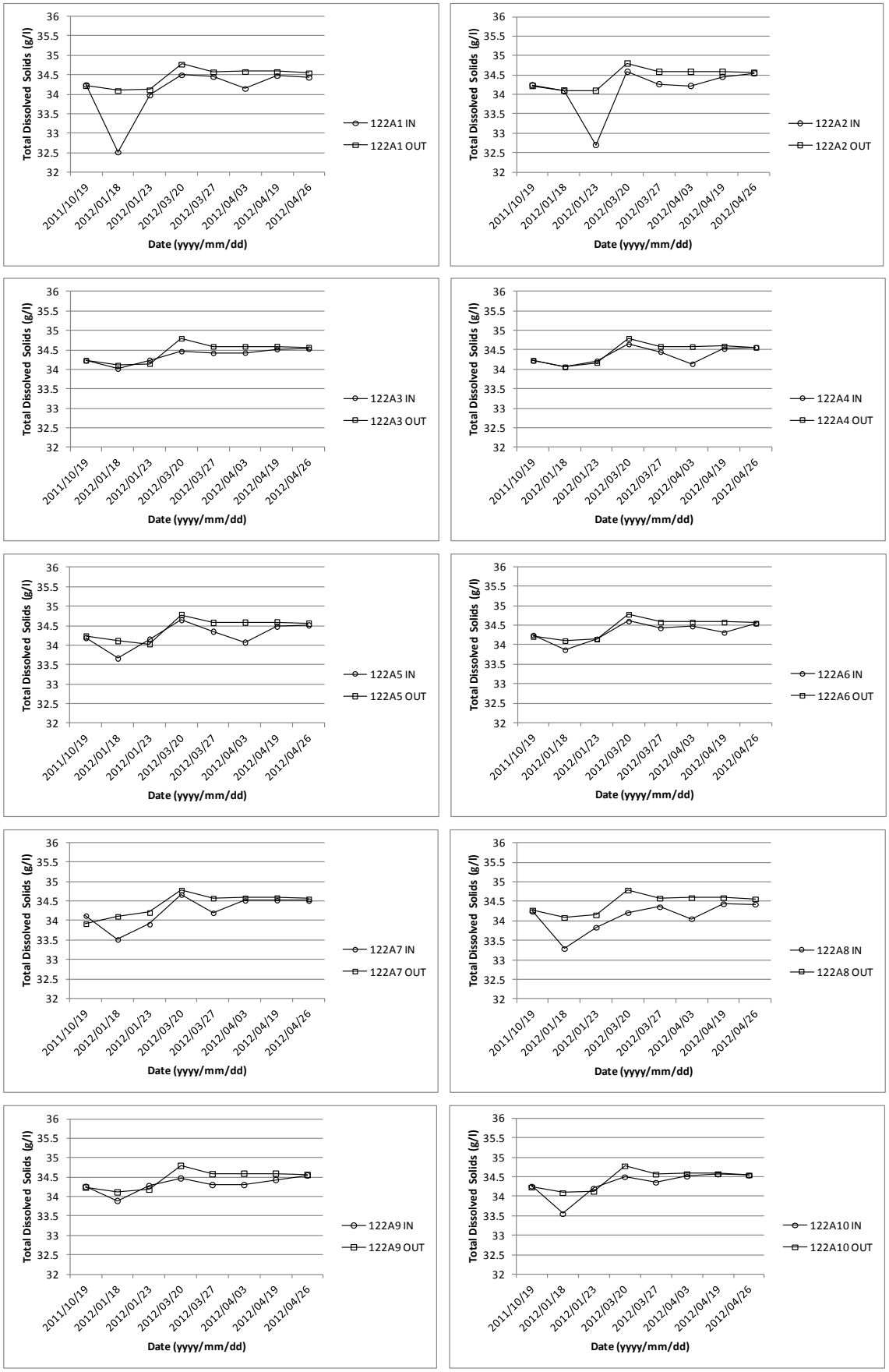


Figure C.1.3.1 *– Row 122A abalone tank TDS*

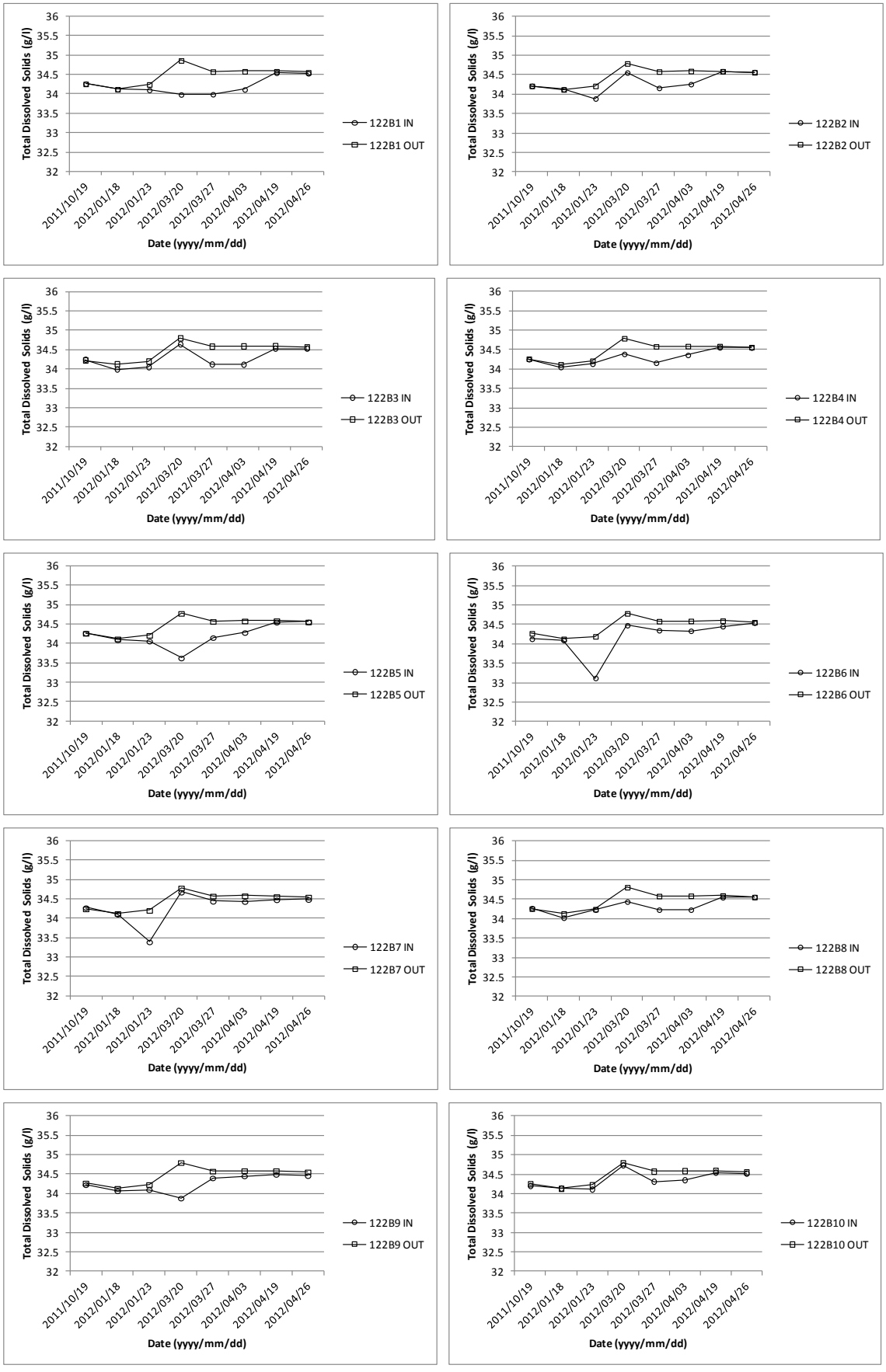


Figure C.1.3.2 *– Row 122B abalone tank TDS*

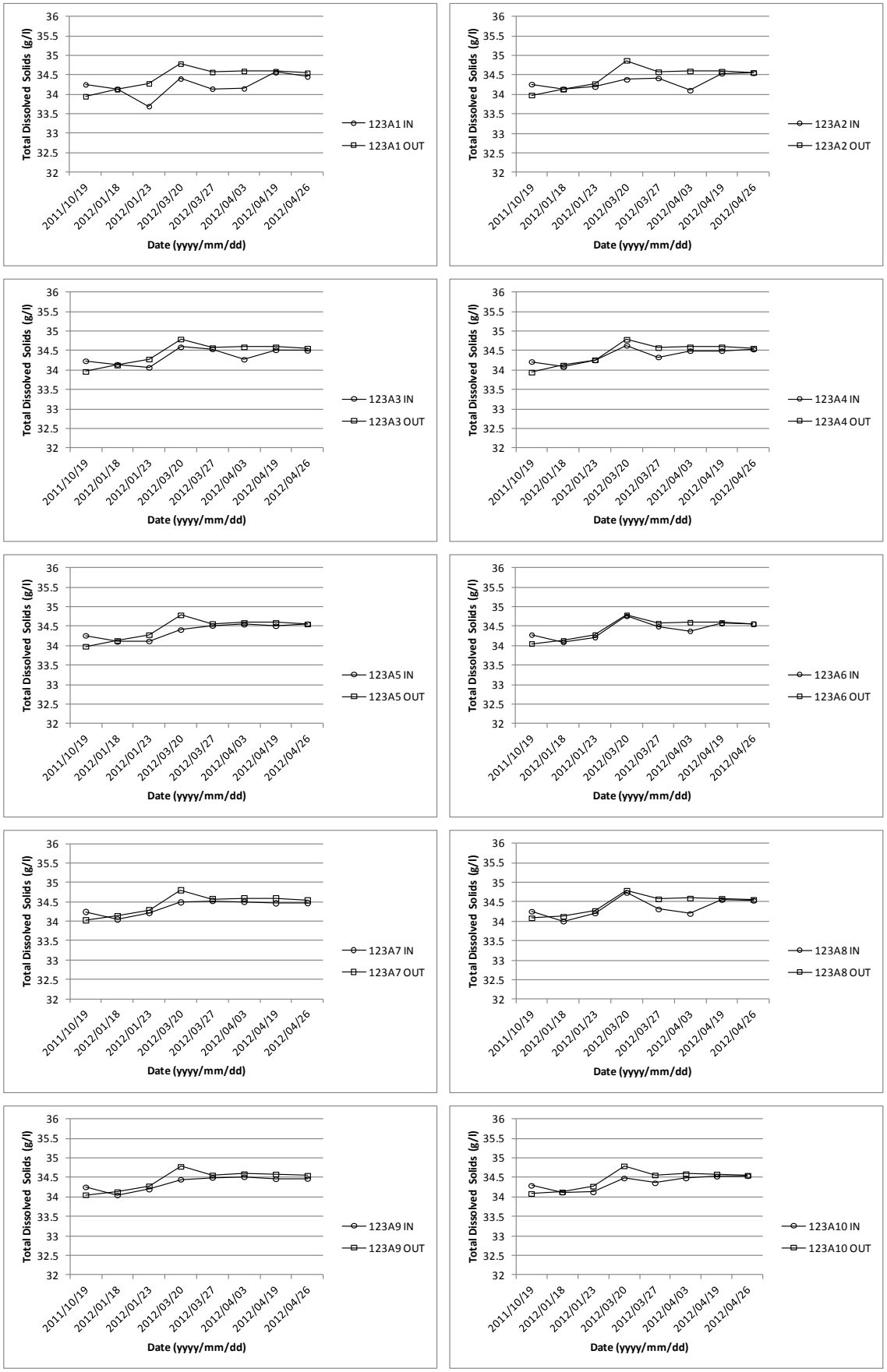


Figure C.1.3.3 *– Row 123A abalone tank TDS*

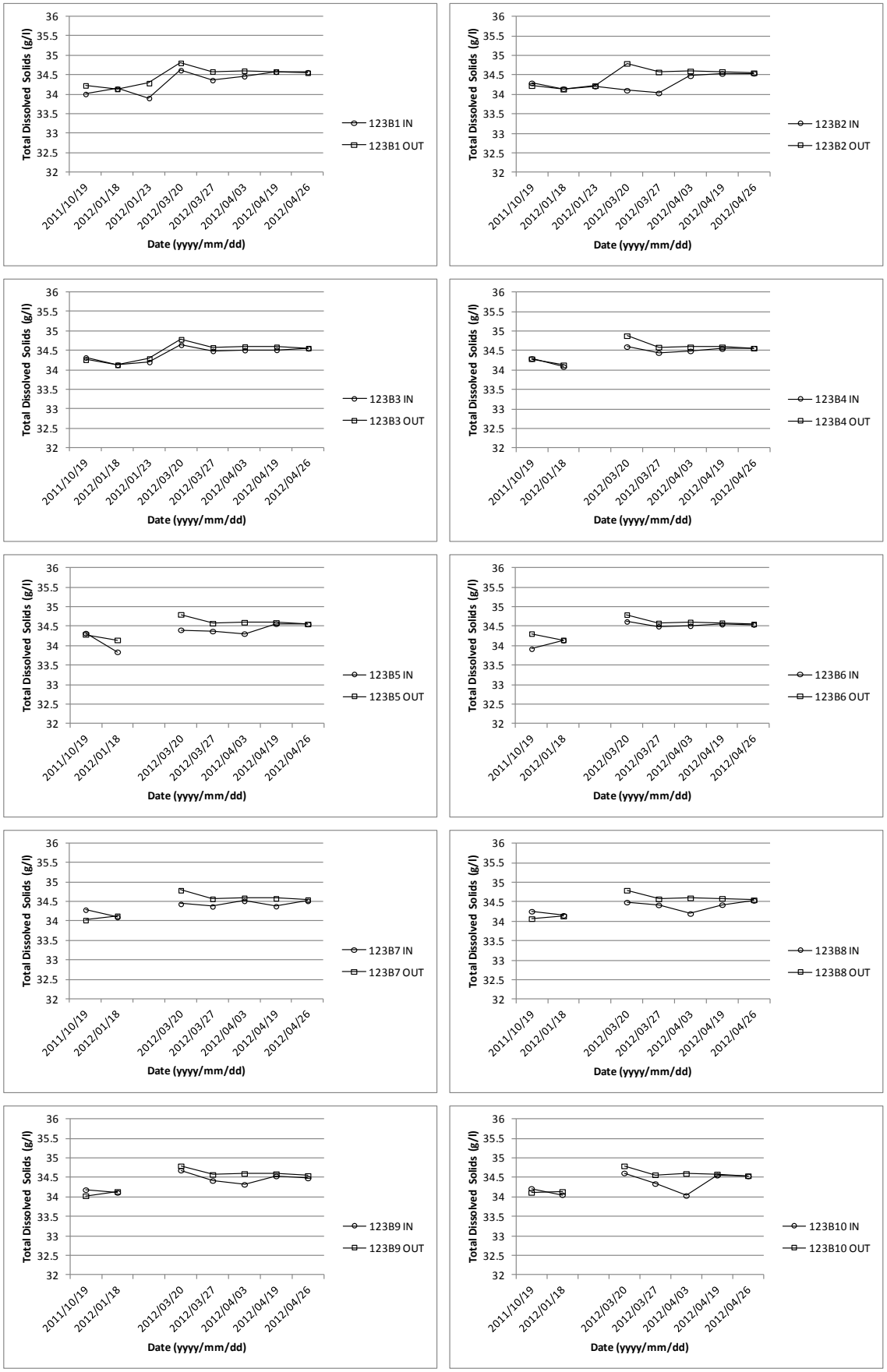


Figure C.1.3.4 *– Row 123B abalone tank TDS*

C.1.4 Salinity

Table C.1.4 (a)-(d) *– Abalone tank salinity*

Site	Timestamp		Salinity (ppt)	
	IN	OUT	IN	OUT
122A1	2011/10/19 09:26	2011/09/27 10:14	34.75	34.71
122A2	2011/10/19 09:29	2011/09/27 10:14	34.74	34.71
122A3	2011/10/19 09:32	2011/09/27 10:14	34.72	34.71
122A4	2011/10/19 09:35	2011/09/27 10:14	34.71	34.71
122A5	2011/10/19 09:38	2011/09/27 10:14	34.67	34.71
122A6	2011/10/19 09:41	2011/09/27 10:14	34.75	34.7
122A7	2011/10/19 09:45	2011/09/27 10:14	34.61	34.36
122A8	2011/10/19 09:48	2011/09/27 10:14	34.73	34.76
122A9	2011/10/19 09:52	2011/09/27 10:14	34.75	34.72
122A10	2011/10/19 09:55	2011/09/27 10:14	34.77	34.73
122B1	2011/10/19 10:02	2011/09/27 10:14	34.77	34.75
122B2	2011/10/19 10:04	2011/09/27 10:14	34.7	34.69
122B3	2011/10/19 10:08	2011/09/27 10:14	34.74	34.71
122B4	2011/10/19 10:11	2011/09/27 10:14	34.75	34.75
122B5	2011/10/19 10:15	2011/09/27 10:14	34.77	34.76
122B6	2011/10/19 10:20	2011/09/27 10:14	34.61	34.76
122B7	2011/10/19 10:23	2011/09/27 10:14	34.78	34.74
122B8	2011/10/19 10:26	2011/09/27 10:14	34.77	34.74
122B9	2011/10/19 10:30	2011/09/27 10:14	34.71	34.76
122B10	2011/10/19 10:32	2011/09/27 10:14	34.69	34.74
123A1	2011/10/19 11:45	2011/09/27 10:14	34.76	34.4
123A2	2011/10/19 11:48	2011/09/27 10:14	34.76	34.44
123A3	2011/10/19 11:52	2011/09/27 10:14	34.74	34.42
123A4	2011/10/19 11:55	2011/09/27 10:14	34.71	34.4
123A5	2011/10/19 11:59	2011/09/27 10:14	34.76	34.44
123A6	2011/10/19 12:02	2011/09/27 10:14	34.78	34.52
123A7	2011/10/19 12:05	2011/09/27 10:14	34.74	34.49
123A8	2011/10/19 12:13	2011/09/27 10:14	34.76	34.55
123A9	2011/10/19 12:15	2011/09/27 10:14	34.76	34.52
123A10	2011/10/19 12:18	2011/09/27 10:14	34.81	34.56
123B1	2011/10/19 12:21	2011/09/27 10:14	34.48	34.72
123B2	2011/10/19 12:23	2011/09/27 10:14	34.8	34.72
123B3	2011/10/19 12:26	2011/09/27 10:14	34.83	34.76
123B4	2011/10/19 12:28	2011/09/27 10:14	34.8	34.79
123B5	2011/10/19 12:30	2011/09/27 10:14	34.83	34.79
123B6	2011/10/19 12:32	2011/09/27 10:14	34.38	34.81
123B7	2011/10/19 12:34	2011/09/27 10:14	34.8	34.5
123B8	2011/10/19 12:37	2011/09/27 10:14	34.76	34.54
123B9	2011/10/19 12:40	2011/09/27 10:14	34.68	34.49
123B10	2011/10/19 12:42	2011/09/27 10:14	34.71	34.59

Site	Timestamp		Salinity (ppt)	
	IN	OUT	IN	OUT
122A1	2012/01/18 09:37	2012/01/18 09:39	32.79	34.58
122A2	2012/01/18 09:40	2012/01/18 09:41	34.56	34.59
122A3	2012/01/18 09:42	2012/01/18 09:43	34.48	34.58
122A4	2012/01/18 09:44	2012/01/18 09:45	34.53	34.53
122A5	2012/01/18 09:46	2012/01/18 09:47	34.08	34.59
122A6	2012/01/18 09:49	2012/01/18 09:50	34.32	34.59
122A7	2012/01/18 09:51	2012/01/18 09:51	33.92	34.59
122A8	2012/01/18 09:54	2012/01/18 09:55	33.65	34.56
122A9	2012/01/18 09:59	2012/01/18 10:00	34.34	34.59
122A10	2012/01/18 10:02	2012/01/18 10:03	33.96	34.58
122B1	2012/01/18 10:23	2012/01/18 10:25	34.61	34.61
122B2	2012/01/18 10:26	2012/01/18 10:27	34.61	34.6
122B3	2012/01/18 10:28	2012/01/18 10:30	34.44	34.61
122B4	2012/01/18 10:31	2012/01/18 10:32	34.51	34.6
122B5	2012/01/18 10:33	2012/01/18 10:35	34.57	34.61
122B6	2012/01/18 10:36	2012/01/18 10:38	34.57	34.61
122B7	2012/01/18 10:40	2012/01/18 10:41	34.59	34.62
122B8	2012/01/18 10:43	2012/01/18 10:44	34.49	34.62
122B9	2012/01/18 10:45	2012/01/18 10:47	34.54	34.62
122B10	2012/01/18 10:48	2012/01/18 10:49	34.63	34.62
123A1	2012/01/18 10:59	2012/01/18 11:00	34.63	34.62
123A2	2012/01/18 11:02	2012/01/18 11:03	34.62	34.62
123A3	2012/01/18 11:05	2012/01/18 11:07	34.63	34.62
123A4	2012/01/18 11:08	2012/01/18 11:09	34.56	34.61
123A5	2012/01/18 11:11	2012/01/18 11:12	34.59	34.62
123A6	2012/01/18 11:13	2012/01/18 11:15	34.58	34.62
123A7	2012/01/18 11:16	2012/01/18 11:17	34.53	34.62
123A8	2012/01/18 11:18	2012/01/18 11:20	34.48	34.62
123A9	2012/01/18 11:21	2012/01/18 11:22	34.53	34.62
123A10	2012/01/18 11:24	2012/01/18 11:25	34.61	34.62
123B1	2012/01/18 11:35	2012/01/18 11:36	34.64	34.63
123B2	2012/01/18 11:38	2012/01/18 11:39	34.64	34.63
123B3	2012/01/18 11:40	2012/01/18 11:41	34.63	34.62
123B4	2012/01/18 11:42	2012/01/18 11:43	34.58	34.63
123B5	2012/01/18 11:45	2012/01/18 11:46	34.3	34.64
123B6	2012/01/18 11:47	2012/01/18 11:49	34.64	34.64
123B7	2012/01/18 11:50	2012/01/18 11:51	34.6	34.63
123B8	2012/01/18 11:52	2012/01/18 11:53	34.65	34.63
123B9	2012/01/18 11:55	2012/01/18 11:56	34.61	34.63
123B10	2012/01/18 11:58	2012/01/18 11:59	34.55	34.63

Site	Timestamp		Salinity (ppt)	
	IN	OUT	IN	OUT
122A1	2012/01/23 12:23	2012/01/23 12:25	34.49	34.64
122A2	2012/01/23 12:26	2012/01/23 12:28	33.03	34.62
122A3	2012/01/23 12:29	2012/01/23 12:31	34.78	34.67
122A4	2012/01/23 12:37	2012/01/23 12:39	34.75	34.7
122A5	2012/01/23 12:43	2012/01/23 12:46	34.67	34.55
122A6	2012/01/23 12:48	2012/01/23 12:49	34.68	34.68
122A7	2012/01/23 12:51	2012/01/23 12:52	34.4	34.74
122A8	2012/01/23 12:54	2012/01/23 12:55	34.31	34.67
122A9	2012/01/23 12:57	2012/01/23 12:59	34.81	34.72
122A10	2012/01/23 13:01	2012/01/23 13:02	34.75	34.66
122B1	2012/01/23 13:06	2012/01/23 13:07	34.62	34.79
122B2	2012/01/23 13:08	2012/01/23 13:10	34.37	34.74
122B3	2012/01/23 13:12	2012/01/23 13:13	34.56	34.73
122B4	2012/01/23 13:15	2012/01/23 13:16	34.65	34.74
122B5	2012/01/23 13:18	2012/01/23 13:19	34.58	34.75
122B6	2012/01/23 13:21	2012/01/23 13:22	33.51	34.72
122B7	2012/01/23 13:23	2012/01/23 13:25	33.82	34.74
122B8	2012/01/23 13:27	2012/01/23 13:28	34.76	34.78
122B9	2012/01/23 13:30	2012/01/23 13:31	34.62	34.76
122B10	2012/01/23 13:32	2012/01/23 13:34	34.63	34.76
123A1	2012/01/23 14:07	2012/01/23 14:08	34.16	34.82
123A2	2012/01/23 14:10	2012/01/23 14:12	34.73	34.82
123A3	2012/01/23 14:14	2012/01/23 14:15	34.58	34.82
123A4	2012/01/23 14:17	2012/01/23 14:23	34.79	34.8
123A5	2012/01/23 14:24	2012/01/23 14:26	34.63	34.82
123A6	2012/01/23 14:30	2012/01/23 14:32	34.75	34.82
123A7	2012/01/23 14:35	2012/01/23 14:37	34.75	34.83
123A8	2012/01/23 14:38	2012/01/23 14:40	34.74	34.82
123A9	2012/01/23 14:43	2012/01/23 14:44	34.73	34.82
123A10	2012/01/23 14:46	2012/01/23 14:47	34.64	34.82
123B1	2012/01/23 14:55	2012/01/23 14:56	34.4	34.83
123B2	2012/01/23 15:00	2012/01/23 15:02	34.74	34.76
123B3	2012/01/23 15:03	2012/01/23 15:05	34.74	34.84
123B4	2012/01/23 15:18	2012/01/23 16:11	34.84	0.02
123B5	2012/01/23 16:13	2012/01/23 16:15	0.02	0.02
123B6	2012/01/23 16:17	2012/01/23 16:19	0.02	0.02
123B7	2012/01/23 16:21	2012/01/23 16:22	34.62	0.03
123B8	2012/01/23 16:26	2012/01/23 16:27	34.8	34.8
123B9	2012/01/23 16:36	2012/01/23 16:38	0.02	0.02
123B10	2012/01/23 16:39	2012/01/23 16:40	0.02	0.02

Site	Timestamp		Salinity (ppt)	
	IN	OUT	IN	OUT
122A1	2012/03/20 11:40	2012/03/20 14:21	35.08	35.39
122A2	2012/03/20 11:42	2012/03/20 14:22	35.17	35.42
122A3	2012/03/20 11:44	2012/03/20 14:24	35.03	35.41
122A4	2012/03/20 11:46	2012/03/20 14:26	35.23	35.41
122A5	2012/03/20 11:49	2012/03/20 14:27	35.24	35.4
122A6	2012/03/20 11:50	2012/03/20 14:28	35.2	35.4
122A7	2012/03/20 11:53	2012/03/20 14:30	35.27	35.4
122A8	2012/03/20 11:55	2012/03/20 14:31	34.74	35.41
122A9	2012/03/20 11:57	2012/03/20 14:31	35.04	35.41
122A10	2012/03/20 11:59	2012/03/20 14:32	35.08	35.4
122B1	2012/03/20 12:11	2012/03/20 15:08	34.49	35.49
122B2	2012/03/20 12:13	2012/03/20 15:09	35.13	35.4
122B3	2012/03/20 12:14	2012/03/20 15:10	35.23	35.41
122B4	2012/03/20 12:15	2012/03/20 15:11	34.94	35.4
122B5	2012/03/20 12:17	2012/03/20 15:12	34.08	35.4
122B6	2012/03/20 12:18	2012/03/20 15:13	35.05	35.4
122B7	2012/03/20 12:19	2012/03/20 15:13	35.27	35.41
122B8	2012/03/20 12:21	2012/03/20 15:14	35	35.42
122B9	2012/03/20 12:22	2012/03/20 15:15	34.36	35.41
122B10	2012/03/20 12:26	2012/03/20 15:16	35.35	35.4
123A1	2012/03/20 12:55	2012/03/20 14:37	34.96	35.4
123A2	2012/03/20 12:54	2012/03/20 14:38	34.94	35.5
123A3	2012/03/20 12:53	2012/03/20 14:39	35.18	35.41
123A4	2012/03/20 12:52	2012/03/20 14:41	35.22	35.4
123A5	2012/03/20 12:51	2012/03/20 14:42	34.97	35.4
123A6	2012/03/20 12:50	2012/03/20 14:43	35.37	35.4
123A7	2012/03/20 12:49	2012/03/20 14:44	35.06	35.41
123A8	2012/03/20 12:47	2012/03/20 14:46	35.34	35.41
123A9	2012/03/20 12:46	2012/03/20 14:47	35.01	35.39
123A10	2012/03/20 12:45	2012/03/20 14:48	35.05	35.41
123B1	2012/03/20 12:32	2012/03/20 14:51	35.2	35.42
123B2	2012/03/20 12:33	2012/03/20 14:52	34.62	35.41
123B3	2012/03/20 12:34	2012/03/20 14:53	35.24	35.41
123B4	2012/03/20 12:35	2012/03/20 14:54	35.19	35.5
123B5	2012/03/20 12:36	2012/03/20 14:54	34.96	35.42
123B6	2012/03/20 12:37	2012/03/20 14:55	35.21	35.41
123B7	2012/03/20 12:38	2012/03/20 14:56	35.01	35.41
123B8	2012/03/20 12:39	2012/03/20 14:57	35.06	35.41
123B9	2012/03/20 12:40	2012/03/20 14:57	35.28	35.41
123B10	2012/03/20 12:42	2012/03/20 14:58	35.2	35.41

Table C.1.4 (e)-(h) *– Abalone tank salinity*

Site	Timestamp		Salinity (ppt)	
	IN	OUT	IN	OUT
122A1	2012/03/27 10:42	2012/03/27 10:55	34.85	35.01
122A2	2012/03/27 10:43	2012/03/27 10:56	34.64	35.01
122A3	2012/03/27 10:44	2012/03/27 10:57	34.8	35.01
122A4	2012/03/27 10:45	2012/03/27 10:58	34.84	35.01
122A5	2012/03/27 10:47	2012/03/27 10:59	34.74	35.01
122A6	2012/03/27 10:48	2012/03/27 11:01	34.84	35.01
122A7	2012/03/27 10:49	2012/03/27 11:01	34.57	35.01
122A8	2012/03/27 10:50	2012/03/27 11:02	34.74	35.01
122A9	2012/03/27 10:52	2012/03/27 11:03	34.68	35.01
122A10	2012/03/27 10:53	2012/03/27 11:04	34.76	35.01
122B1	2012/03/27 11:06	2012/03/27 11:20	34.33	35.01
122B2	2012/03/27 11:08	2012/03/27 11:21	34.51	35.01
122B3	2012/03/27 11:09	2012/03/27 11:22	34.47	35.01
122B4	2012/03/27 11:11	2012/03/27 11:23	34.51	35.01
122B5	2012/03/27 11:12	2012/03/27 11:23	34.52	35.01
122B6	2012/03/27 11:13	2012/03/27 11:24	34.73	35.01
122B7	2012/03/27 11:14	2012/03/27 11:25	34.83	35.01
122B8	2012/03/27 11:15	2012/03/27 11:26	34.6	35.01
122B9	2012/03/27 11:16	2012/03/27 11:27	34.79	35.01
122B10	2012/03/27 11:17	2012/03/27 11:28	34.7	35.01
123A1	2012/03/27 11:44	2012/03/27 11:56	34.5	35.01
123A2	2012/03/27 11:45	2012/03/27 11:57	34.8	35.01
123A3	2012/03/27 11:47	2012/03/27 11:57	34.95	35.01
123A4	2012/03/27 11:48	2012/03/27 11:58	34.71	35.01
123A5	2012/03/27 11:49	2012/03/27 11:59	34.92	35.01
123A6	2012/03/27 11:50	2012/03/27 12:01	34.89	35.01
123A7	2012/03/27 11:51	2012/03/27 12:02	34.93	35.01
123A8	2012/03/27 11:52	2012/03/27 12:03	34.69	35.01
123A9	2012/03/27 11:53	2012/03/27 12:04	34.89	35
123A10	2012/03/27 11:54	2012/03/27 12:04	34.74	35.02
123B1	2012/03/27 14:15	2012/03/27 14:29	34.79	35.02
123B2	2012/03/27 14:16	2012/03/27 14:30	34.41	35.02
123B3	2012/03/27 14:19	2012/03/27 14:30	34.92	35.01
123B4	2012/03/27 14:20	2012/03/27 14:31	34.88	35.02
123B5	2012/03/27 14:21	2012/03/27 14:32	34.8	35.02
123B6	2012/03/27 14:22	2012/03/27 14:52	34.94	35.02
123B7	2012/03/27 14:23	2012/03/27 14:53	34.81	35.02
123B8	2012/03/27 14:24	2012/03/27 14:53	34.86	35.02
123B9	2012/03/27 14:25	2012/03/27 14:54	34.86	35.01
123B10	2012/03/27 14:26	2012/03/27 14:55	34.77	35.01

Site	Timestamp		Salinity (ppt)	
	IN	OUT	IN	OUT
122A1	2012/04/03 11:12	2012/04/03 11:25	34.63	35.13
122A2	2012/04/03 11:13	2012/04/03 11:27	34.7	35.13
122A3	2012/04/03 11:14	2012/04/03 11:28	34.94	35.13
122A4	2012/04/03 11:15	2012/04/03 11:29	34.61	35.12
122A5	2012/04/03 11:16	2012/04/03 11:30	34.54	35.13
122A6	2012/04/03 11:17	2012/04/03 11:32	35.01	35.13
122A7	2012/04/03 11:18	2012/04/03 11:33	35.05	35.13
122A8	2012/04/03 11:20	2012/04/03 11:34	34.52	35.13
122A9	2012/04/03 11:21	2012/04/03 11:35	34.8	35.13
122A10	2012/04/03 11:22	2012/04/03 11:36	35.05	35.13
122B1	2012/04/03 12:08	2012/04/03 12:20	34.59	35.13
122B2	2012/04/03 12:09	2012/04/03 12:21	34.75	35.13
122B3	2012/04/03 12:11	2012/04/03 12:22	34.59	35.13
122B4	2012/04/03 12:13	2012/04/03 12:23	34.86	35.13
122B5	2012/04/03 12:13	2012/04/03 12:23	34.78	35.13
122B6	2012/04/03 12:14	2012/04/03 12:24	34.83	35.13
122B7	2012/04/03 12:15	2012/04/03 12:25	34.95	35.13
122B8	2012/04/03 12:16	2012/04/03 12:26	34.71	35.13
122B9	2012/04/03 12:17	2012/04/03 12:26	34.97	35.13
122B10	2012/04/03 12:18	2012/04/03 12:27	34.86	35.13
123A1	2012/04/03 14:49	2012/04/03 14:59	34.66	35.16
123A2	2012/04/03 14:50	2012/04/03 15:00	34.61	35.17
123A3	2012/04/03 14:51	2012/04/03 15:01	34.8	35.16
123A4	2012/04/03 14:52	2012/04/03 15:02	35.06	35.16
123A5	2012/04/03 14:53	2012/04/03 15:03	35.12	35.16
123A6	2012/04/03 14:54	2012/04/03 15:04	34.92	35.17
123A7	2012/04/03 14:55	2012/04/03 15:05	35.06	35.16
123A8	2012/04/03 14:56	2012/04/03 15:05	34.71	35.16
123A9	2012/04/03 14:57	2012/04/03 15:06	35.08	35.16
123A10	2012/04/03 14:57	2012/04/03 15:07	35.04	35.16
123B1	2012/04/03 15:27	2012/04/03 15:51	35.02	35.18
123B2	2012/04/03 15:28	2012/04/03 15:52	35.04	35.18
123B3	2012/04/03 15:29	2012/04/03 15:53	35.07	35.18
123B4	2012/04/03 15:30	2012/04/03 15:53	35.05	35.17
123B5	2012/04/03 15:31	2012/04/03 15:54	34.84	35.18
123B6	2012/04/03 15:32	2012/04/03 15:55	35.07	35.18
123B7	2012/04/03 15:33	2012/04/03 15:56	35.08	35.18
123B8	2012/04/03 15:34	2012/04/03 15:57	34.72	35.18
123B9	2012/04/03 15:35	2012/04/03 15:57	34.86	35.18
123B10	2012/04/03 15:36	2012/04/03 15:58	34.53	35.18

Site	Timestamp		Salinity (ppt)	
	IN	OUT	IN	OUT
122A1	2012/04/19 10:52	2012/04/19 11:16	34.99	35.11
122A2	2012/04/19 10:53	2012/04/19 11:17	34.96	35.12
122A3	2012/04/19 10:54	2012/04/19 11:17	35.03	35.12
122A4	2012/04/19 10:55	2012/04/19 11:18	35.04	35.12
122A5	2012/04/19 10:56	2012/04/19 11:19	34.99	35.12
122A6	2012/04/19 10:57	2012/04/19 11:20	34.81	35.12
122A7	2012/04/19 10:58	2012/04/19 11:21	35.04	35.12
122A8	2012/04/19 11:00	2012/04/19 11:22	34.94	35.12
122A9	2012/04/19 11:01	2012/04/19 11:22	34.93	35.12
122A10	2012/04/19 11:02	2012/04/19 11:24	35.1	35.12
122B1	2012/04/19 11:04	2012/04/19 11:25	35.06	35.11
122B2	2012/04/19 11:05	2012/04/19 11:26	35.11	35.12
122B3	2012/04/19 11:06	2012/04/19 11:27	35.04	35.12
122B4	2012/04/19 11:07	2012/04/19 11:28	35.07	35.11
122B5	2012/04/19 11:08	2012/04/19 11:28	35.07	35.12
122B6	2012/04/19 11:09	2012/04/19 11:29	34.96	35.12
122B7	2012/04/19 11:10	2012/04/19 11:29	34.99	35.09
122B8	2012/04/19 11:11	2012/04/19 11:30	35.07	35.12
122B9	2012/04/19 11:12	2012/04/19 11:31	35	35.12
122B10	2012/04/19 11:13	2012/04/19 11:31	35.07	35.12
123A1	2012/04/19 11:41	2012/04/19 12:10	35.09	35.12
123A2	2012/04/19 11:41	2012/04/19 12:11	35.06	35.12
123A3	2012/04/19 11:42	2012/04/19 12:11	35.03	35.12
123A4	2012/04/19 11:43	2012/04/19 12:12	35.01	35.12
123A5	2012/04/19 11:44	2012/04/19 12:13	35.02	35.12
123A6	2012/04/19 11:45	2012/04/19 12:13	35.09	35.12
123A7	2012/04/19 11:46	2012/04/19 12:14	34.97	35.12
123A8	2012/04/19 11:47	2012/04/19 12:23	35.07	35.12
123A9	2012/04/19 11:48	2012/04/19 12:23	34.97	35.12
123A10	2012/04/19 11:49	2012/04/19 12:24	35.04	35.12
123B1	2012/04/19 11:53	2012/04/19 12:25	35.1	35.12
123B2	2012/04/19 11:54	2012/04/19 12:26	35.05	35.12
123B3	2012/04/19 11:55	2012/04/19 12:26	35.03	35.12
123B4	2012/04/19 11:56	2012/04/19 12:27	35.06	35.12
123B5	2012/04/19 11:57	2012/04/19 12:28	35.09	35.13
123B6	2012/04/19 11:58	2012/04/19 12:28	35.07	35.12
123B7	2012/04/19 11:59	2012/04/19 12:29	34.88	35.12
123B8	2012/04/19 11:59	2012/04/19 12:29	34.92	35.12
123B9	2012/04/19 12:00	2012/04/19 12:30	35.06	35.12
123B10	2012/04/19 12:01	2012/04/19 12:31	35.08	35.12

Site	Timestamp		Salinity (ppt)	
	IN	OUT	IN	OUT
122A1	2012/04/26 11:00	2012/04/26 12:57	34.77	34.93
122A2	2012/04/26 11:01	2012/04/26 12:57	34.89	34.93
122A3	2012/04/26 11:02	2012/04/26 12:59	34.87	34.94
122A4	2012/04/26 11:04	2012/04/26 12:59	34.91	34.93
122A5	2012/04/26 11:05	2012/04/26 13:00	34.86	34.93
122A6	2012/04/26 11:06	2012/04/26 13:01	34.9	34.93
122A7	2012/04/26 11:07	2012/04/26 13:02	34.86	34.93
122A8	2012/04/26 11:08	2012/04/26 13:03	34.76	34.93
122A9	2012/04/26 11:10	2012/04/26 13:04	34.89	34.93
122A10	2012/04/26 11:11	2012/04/26 13:04	34.9	34.93
122B1	2012/04/26 11:25	2012/04/26 13:06	34.88	34.93
122B2	2012/04/26 11:26	2012/04/26 13:07	34.91	34.93
122B3	2012/04/26 11:28	2012/04/26 13:08	34.87	34.93
122B4	2012/04/26 11:29	2012/04/26 13:09	34.9	34.93
122B5	2012/04/26 11:31	2012/04/26 13:10	34.91	34.93
122B6	2012/04/26 11:32	2012/04/26 13:10	34.89	34.93
122B7	2012/04/26 11:33	2012/04/26 13:11	34.83	34.93
122B8	2012/04/26 11:34	2012/04/26 13:12	34.91	34.93
122B9	2012/04/26 11:35	2012/04/26 13:12	34.79	34.93
122B10	2012/04/26 11:36	2012/04/26 13:13	34.87	34.93
123A1	2012/04/26 11:41	2012/04/26 13:24	34.79	34.93
123A2	2012/04/26 11:42	2012/04/26 13:24	34.9	34.93
123A3	2012/04/26 11:43	2012/04/26 13:25	34.85	34.93
123A4	2012/04/26 11:44	2012/04/26 13:26	34.88	34.93
123A5	2012/04/26 11:46	2012/04/26 13:27	34.91	34.93
123A6	2012/04/26 11:47	2012/04/26 13:28	34.91	34.93
123A7	2012/04/26 11:48	2012/04/26 13:28	34.81	34.93
123A8	2012/04/26 11:49	2012/04/26 13:29	34.88	34.94
123A9	2012/04/26 11:50	2012/04/26 13:30	34.82	34.93
123A10	2012/04/26 11:51	2012/04/26 13:31	34.9	34.94
123B1	2012/04/26 11:54	2012/04/26 13:32	34.92	34.94
123B2	2012/04/26 11:55	2012/04/26 13:33	34.88	34.93
123B3	2012/04/26 11:56	2012/04/26 13:34	34.9	34.94
123B4	2012/04/26 11:57	2012/04/26 13:35	34.91	34.94
123B5	2012/04/26 11:59	2012/04/26 13:35	34.91	34.94
123B6	2012/04/26 12:00	2012/04/26 13:37	34.89	34.94
123B7	2012/04/26 12:01	2012/04/26 13:37	34.87	34.94
123B8	2012/04/26 12:02	2012/04/26 13:38	34.89	34.94
123B9	2012/04/26 12:02	2012/04/26 13:39	34.83	34.94
123B10	2012/04/26 12:03	2012/04/26 13:39	34.89	34.93

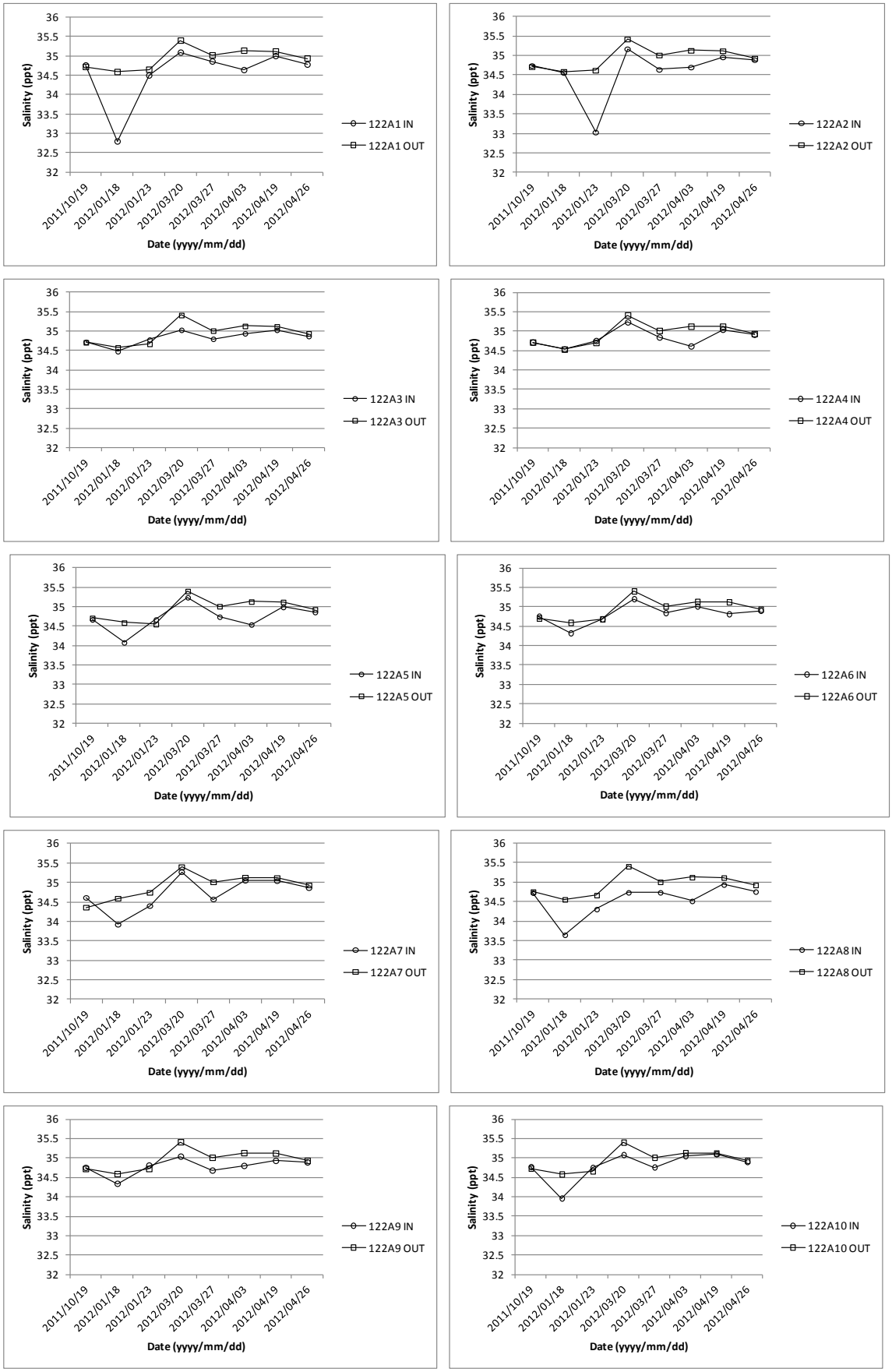


Figure C.1.4.1 *– Row 122A abalone tank salinity*

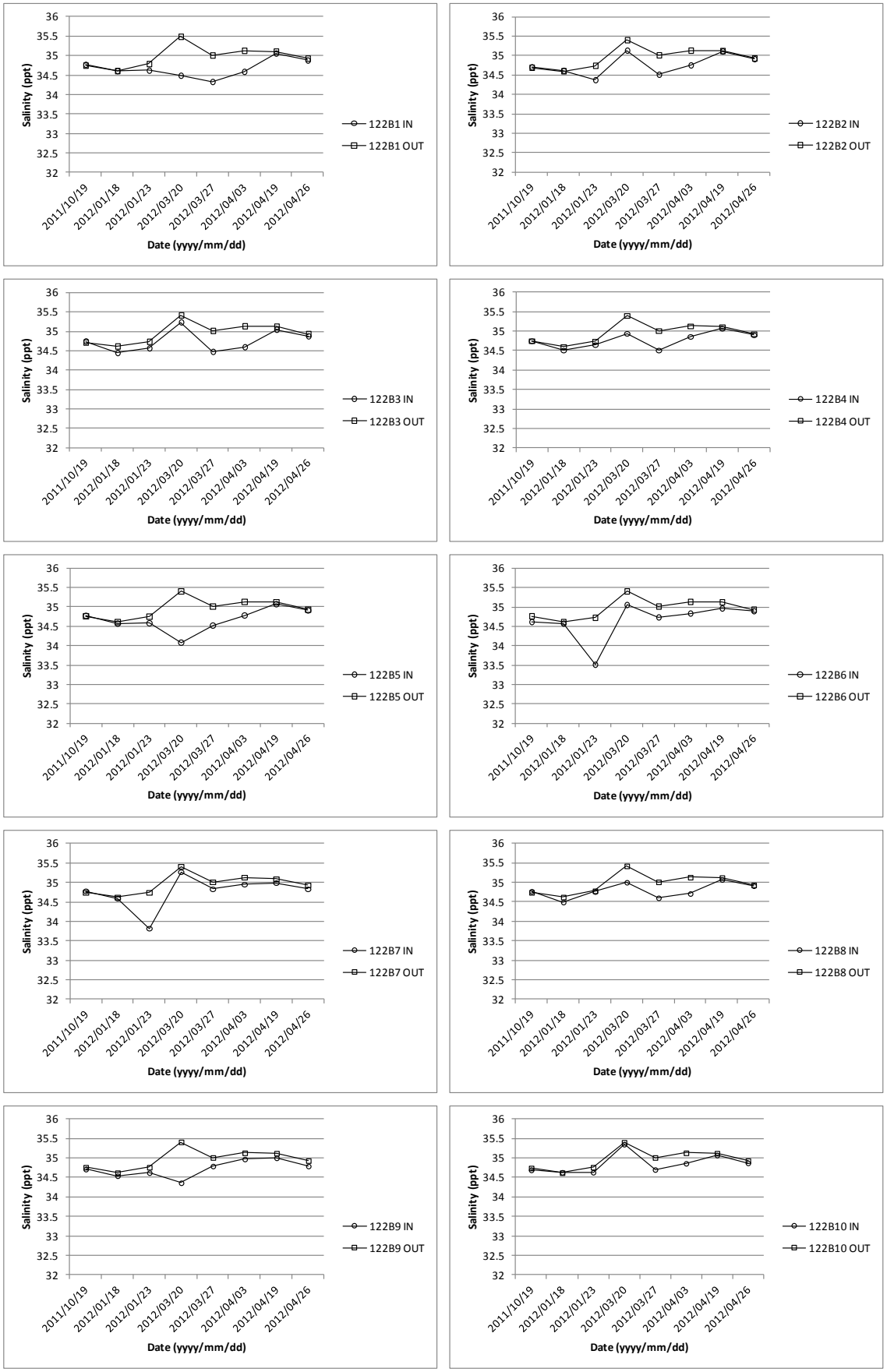


Figure C.1.4.2 *– Row 122B abalone tank salinity*

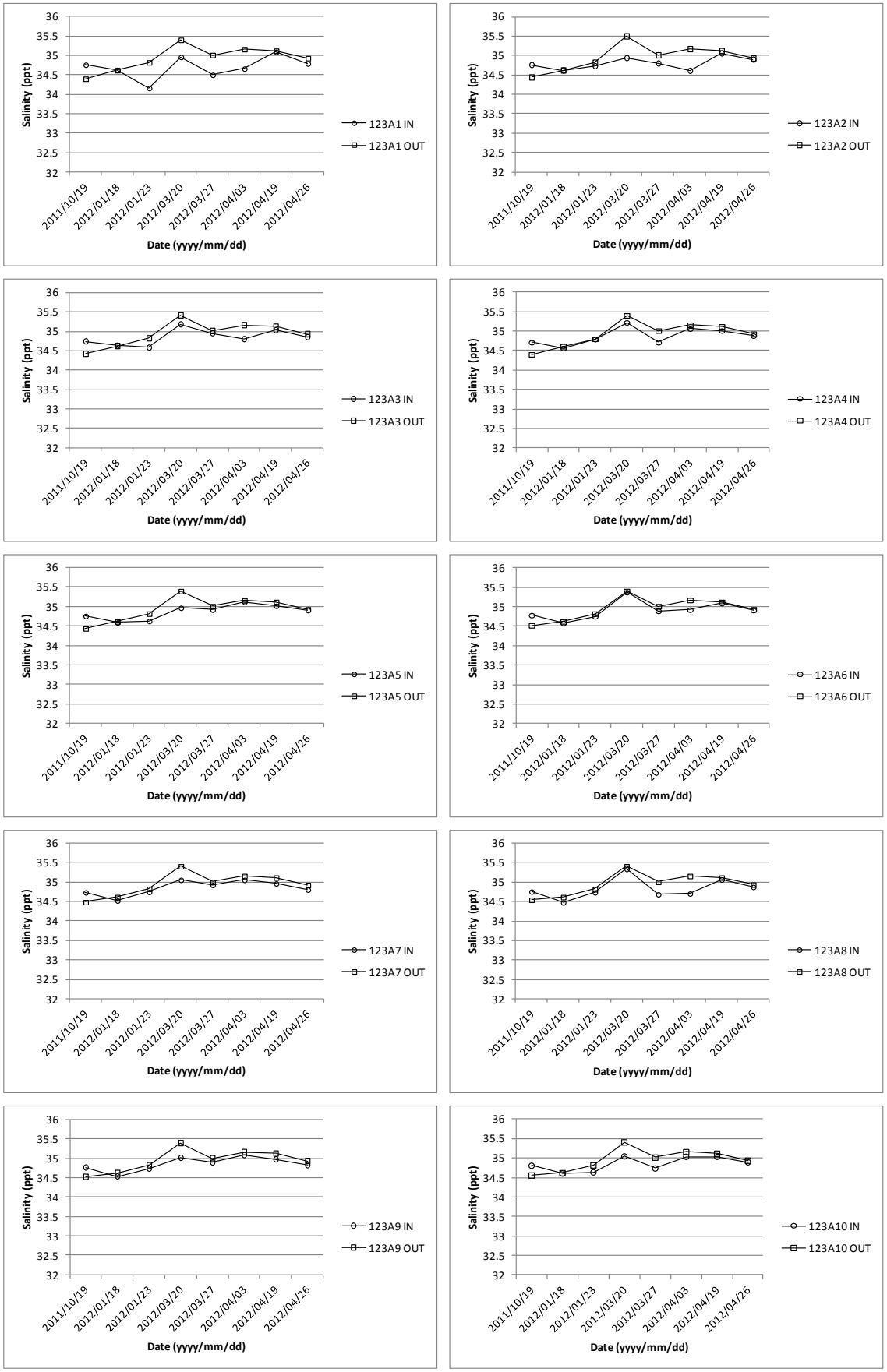


Figure C.1.4.3 *– Row 123A abalone tank salinity*

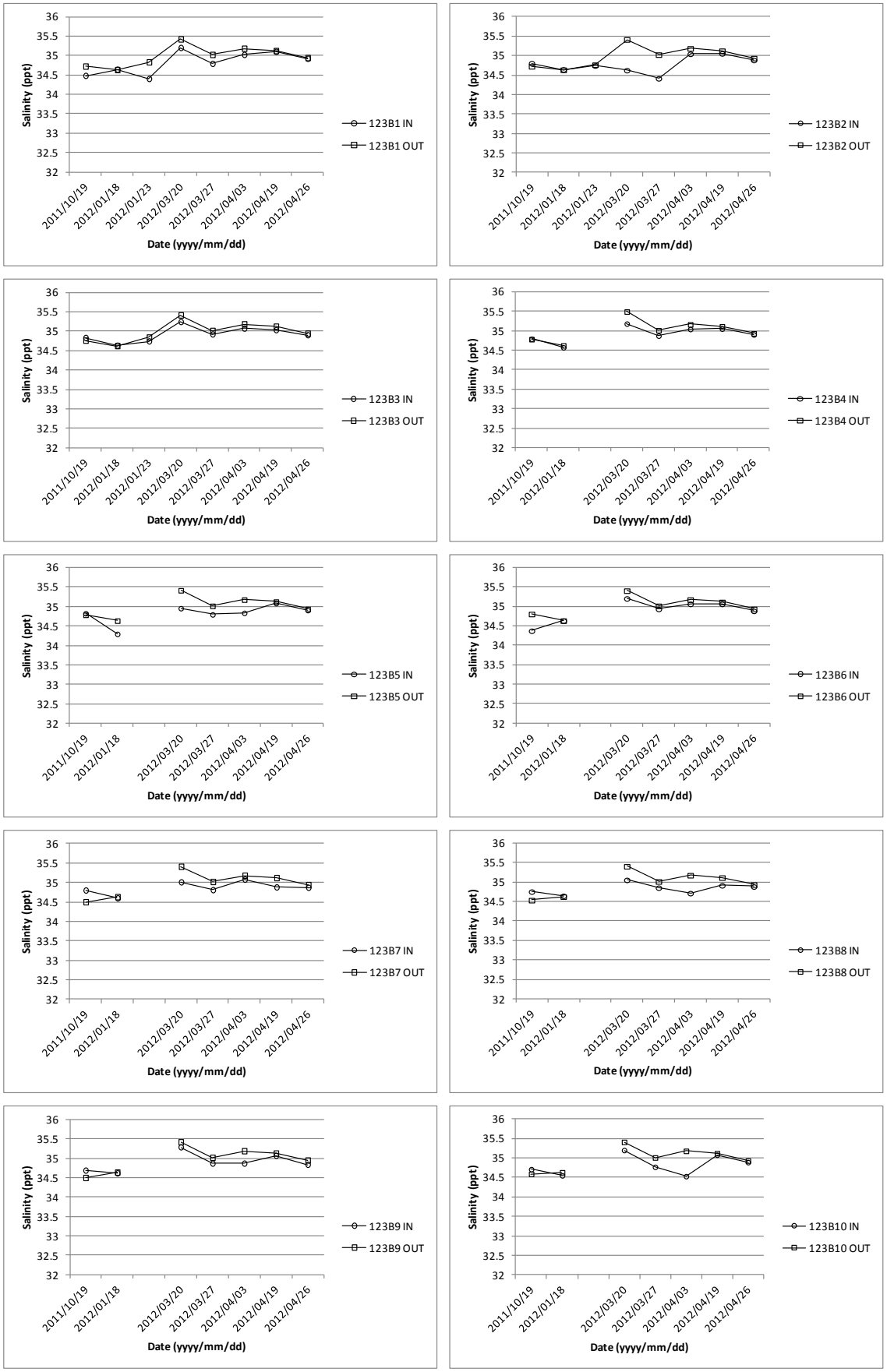


Figure C.1.4.4 *– Row 123B abalone tank salinity*

C.1.5 Dissolved Oxygen

Table C.1.5 (a)-(d) *– Abalone tank dissolved oxygen*

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2011/10/19 09:26	2011/09/27 10:14	7.88	7
122A2	2011/10/19 09:29	2011/09/27 10:14	7.65	6.73
122A3	2011/10/19 09:32	2011/09/27 10:14	7.68	6.78
122A4	2011/10/19 09:35	2011/09/27 10:14	7.66	6.64
122A5	2011/10/19 09:38	2011/09/27 10:14	7.66	6.62
122A6	2011/10/19 09:41	2011/09/27 10:14	7.51	6.78
122A7	2011/10/19 09:45	2011/09/27 10:14	7.65	6.97
122A8	2011/10/19 09:48	2011/09/27 10:14	7.5	6.92
122A9	2011/10/19 09:52	2011/09/27 10:14	7.51	6.94
122A10	2011/10/19 09:55	2011/09/27 10:14	7.6	7.22
122B1	2011/10/19 10:02	2011/09/27 10:14	7.58	7.14
122B2	2011/10/19 10:04	2011/09/27 10:14	7.59	6.81
122B3	2011/10/19 10:08	2011/09/27 10:14	7.59	6.66
122B4	2011/10/19 10:11	2011/09/27 10:14	7.58	6.65
122B5	2011/10/19 10:15	2011/09/27 10:14	7.4	6.54
122B6	2011/10/19 10:20	2011/09/27 10:14	7.58	6.86
122B7	2011/10/19 10:23	2011/09/27 10:14	7.5	7.26
122B8	2011/10/19 10:26	2011/09/27 10:14	7.5	6.66
122B9	2011/10/19 10:30	2011/09/27 10:14	7.48	6.94
122B10	2011/10/19 10:32	2011/09/27 10:14	7.51	7.11
123A1	2011/10/19 11:45	2011/09/27 10:14	7.37	6.67
123A2	2011/10/19 11:48	2011/09/27 10:14	7.44	6.85
123A3	2011/10/19 11:52	2011/09/27 10:14	7.48	6.74
123A4	2011/10/19 11:55	2011/09/27 10:14	7.53	6.69
123A5	2011/10/19 11:59	2011/09/27 10:14	7.58	7.01
123A6	2011/10/19 12:02	2011/09/27 10:14	7.43	7.08
123A7	2011/10/19 12:05	2011/09/27 10:14	7.52	7.43
123A8	2011/10/19 12:13	2011/09/27 10:14	7.37	7.19
123A9	2011/10/19 12:15	2011/09/27 10:14	7.4	7.01
123A10	2011/10/19 12:18	2011/09/27 10:14	7.49	7.17
123B1	2011/10/19 12:21	2011/09/27 10:14	7.53	7.02
123B2	2011/10/19 12:23	2011/09/27 10:14	7.42	6.78
123B3	2011/10/19 12:26	2011/09/27 10:14	7.42	6.86
123B4	2011/10/19 12:28	2011/09/27 10:14	7.46	7.01
123B5	2011/10/19 12:30	2011/09/27 10:14	7.46	7.15
123B6	2011/10/19 12:32	2011/09/27 10:14	7.55	7.09
123B7	2011/10/19 12:34	2011/09/27 10:14	7.43	7.13
123B8	2011/10/19 12:37	2011/09/27 10:14	7.54	7.18
123B9	2011/10/19 12:40	2011/09/27 10:14	7.43	7.32
123B10	2011/10/19 12:42	2011/09/27 10:14	7.6	7.13

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/01/18 09:37	2012/01/18 09:39	7.62	6.94
122A2	2012/01/18 09:40	2012/01/18 09:41	7.34	6.9
122A3	2012/01/18 09:42	2012/01/18 09:43	7.38	6.81
122A4	2012/01/18 09:44	2012/01/18 09:45	7.34	6.89
122A5	2012/01/18 09:46	2012/01/18 09:47	7.5	7.61
122A6	2012/01/18 09:49	2012/01/18 09:50	7.57	7.04
122A7	2012/01/18 09:51	2012/01/18 09:51	7.48	7.19
122A8	2012/01/18 09:54	2012/01/18 09:55	7.49	6.82
122A9	2012/01/18 09:59	2012/01/18 10:00	7.44	6.98
122A10	2012/01/18 10:02	2012/01/18 10:03	7.52	7.23
122B1	2012/01/18 10:23	2012/01/18 10:25	7.52	6.86
122B2	2012/01/18 10:26	2012/01/18 10:27	7.46	6.94
122B3	2012/01/18 10:28	2012/01/18 10:30	7.32	6.75
122B4	2012/01/18 10:31	2012/01/18 10:32	7.55	6.83
122B5	2012/01/18 10:33	2012/01/18 10:35	7.52	6.79
122B6	2012/01/18 10:36	2012/01/18 10:38	7.52	6.68
122B7	2012/01/18 10:40	2012/01/18 10:41	7.7	6.82
122B8	2012/01/18 10:43	2012/01/18 10:44	7.57	6.98
122B9	2012/01/18 10:45	2012/01/18 10:47	7.39	6.88
122B10	2012/01/18 10:48	2012/01/18 10:49	7.56	7.16
123A1	2012/01/18 10:59	2012/01/18 11:00	7.45	6.9
123A2	2012/01/18 11:02	2012/01/18 11:03	7.45	7.01
123A3	2012/01/18 11:05	2012/01/18 11:07	7.51	7.02
123A4	2012/01/18 11:08	2012/01/18 11:09	7.58	7.28
123A5	2012/01/18 11:11	2012/01/18 11:12	7.54	7.48
123A6	2012/01/18 11:13	2012/01/18 11:15	7.51	7.36
123A7	2012/01/18 11:16	2012/01/18 11:17	7.56	7.04
123A8	2012/01/18 11:18	2012/01/18 11:20	7.51	6.91
123A9	2012/01/18 11:21	2012/01/18 11:22	7.53	7.06
123A10	2012/01/18 11:24	2012/01/18 11:25	7.49	7.12
123B1	2012/01/18 11:35	2012/01/18 11:36	7.43	7.19
123B2	2012/01/18 11:38	2012/01/18 11:39	7.43	6.76
123B3	2012/01/18 11:40	2012/01/18 11:41	7.42	6.92
123B4	2012/01/18 11:42	2012/01/18 11:43	7.4	7
123B5	2012/01/18 11:45	2012/01/18 11:46	7.51	7.02
123B6	2012/01/18 11:47	2012/01/18 11:49	7.49	6.89
123B7	2012/01/18 11:50	2012/01/18 11:51	7.5	6.97
123B8	2012/01/18 11:52	2012/01/18 11:53	7.55	6.9
123B9	2012/01/18 11:55	2012/01/18 11:56	7.46	6.95
123B10	2012/01/18 11:58	2012/01/18 11:59	7.47	7.01

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/01/23 12:23	2012/01/23 12:25	7.19	6.16
122A2	2012/01/23 12:26	2012/01/23 12:28	7.01	6.05
122A3	2012/01/23 12:29	2012/01/23 12:31	7.01	5.84
122A4	2012/01/23 12:37	2012/01/23 12:39	7.01	5.92
122A5	2012/01/23 12:43	2012/01/23 12:46	7.3	7.01
122A6	2012/01/23 12:48	2012/01/23 12:49	7.07	6.03
122A7	2012/01/23 12:51	2012/01/23 12:52	7.21	6.18
122A8	2012/01/23 12:54	2012/01/23 12:55	7.06	5.98
122A9	2012/01/23 12:57	2012/01/23 12:59	7.12	6.06
122A10	2012/01/23 13:01	2012/01/23 13:02	7.26	6.42
122B1	2012/01/23 13:06	2012/01/23 13:07	7.07	6.32
122B2	2012/01/23 13:08	2012/01/23 13:10	7.07	6.33
122B3	2012/01/23 13:12	2012/01/23 13:13	7.13	5.84
122B4	2012/01/23 13:15	2012/01/23 13:16	7.13	5.96
122B5	2012/01/23 13:18	2012/01/23 13:19	7.13	5.88
122B6	2012/01/23 13:21	2012/01/23 13:22	7.07	5.9
122B7	2012/01/23 13:23	2012/01/23 13:25	7.17	5.79
122B8	2012/01/23 13:27	2012/01/23 13:28	7.04	6.02
122B9	2012/01/23 13:30	2012/01/23 13:31	7.09	5.96
122B10	2012/01/23 13:32	2012/01/23 13:34	6.96	6.36
123A1	2012/01/23 14:07	2012/01/23 14:08	7.23	6.3
123A2	2012/01/23 14:10	2012/01/23 14:12	7.08	6.38
123A3	2012/01/23 14:14	2012/01/23 14:15	7.11	6.31
123A4	2012/01/23 14:17	2012/01/23 14:23	7.03	6.52
123A5	2012/01/23 14:24	2012/01/23 14:26	7.08	6.69
123A6	2012/01/23 14:30	2012/01/23 14:32	7.04	6.6
123A7	2012/01/23 14:35	2012/01/23 14:37	7.13	6.17
123A8	2012/01/23 14:38	2012/01/23 14:40	7.09	6.12
123A9	2012/01/23 14:43	2012/01/23 14:44	7.16	6.22
123A10	2012/01/23 14:46	2012/01/23 14:47	7.13	6.38
123B1	2012/01/23 14:55	2012/01/23 14:56	7.38	6.56
123B2	2012/01/23 15:00	2012/01/23 15:02	7.1	5.91
123B3	2012/01/23 15:03	2012/01/23 15:05	7.19	6.17
123B4	2012/01/23 15:18	2012/01/23 16:11	7.02	7.59
123B5	2012/01/23 16:13	2012/01/23 16:15	8.59	7.44
123B6	2012/01/23 16:17	2012/01/23 16:19	8.59	7.64
123B7	2012/01/23 16:21	2012/01/23 16:22	7.08	7.69
123B8	2012/01/23 16:26	2012/01/23 16:27	6.92	6.19
123B9	2012/01/23 16:36	2012/01/23 16:38	8.53	7.48
123B10	2012/01/23 16:39	2012/01/23 16:40	8.65	7.62

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/03/20 11:40	2012/03/20 14:21	7.7	6.86
122A2	2012/03/20 11:42	2012/03/20 14:22	8.01	6.85
122A3	2012/03/20 11:44	2012/03/20 14:24	7.95	6.65
122A4	2012/03/20 11:46	2012/03/20 14:26	7.86	6.35
122A5	2012/03/20 11:49	2012/03/20 14:27	8.14	8.11
122A6	2012/03/20 11:50	2012/03/20 14:28	8	6.66
122A7	2012/03/20 11:53	2012/03/20 14:30	7.9	7.09
122A8	2012/03/20 11:55	2012/03/20 14:31	7.89	6.38
122A9	2012/03/20 11:57	2012/03/20 14:31	8.36	6.64
122A10	2012/03/20 11:59	2012/03/20 14:32	7.81	7.12
122B1	2012/03/20 12:11	2012/03/20 15:08	8.14	7.62
122B2	2012/03/20 12:13	2012/03/20 15:09	8.2	7.51
122B3	2012/03/20 12:14	2012/03/20 15:10	8.03	7.18
122B4	2012/03/20 12:15	2012/03/20 15:11	8.11	7.46
122B5	2012/03/20 12:17	2012/03/20 15:12	7.96	7.77
122B6	2012/03/20 12:18	2012/03/20 15:13	7.97	8.06
122B7	2012/03/20 12:19	2012/03/20 15:13	7.89	6.67
122B8	2012/03/20 12:21	2012/03/20 15:14	7.99	6.58
122B9	2012/03/20 12:22	2012/03/20 15:15	7.91	6.72
122B10	2012/03/20 12:26	2012/03/20 15:16	7.93	7.5
123A1	2012/03/20 12:55	2012/03/20 14:37	8.13	7.31
123A2	2012/03/20 12:54	2012/03/20 14:38	8.26	7.64
123A3	2012/03/20 12:53	2012/03/20 14:39	7.91	7.57
123A4	2012/03/20 12:52	2012/03/20 14:41	8.26	7.66
123A5	2012/03/20 12:51	2012/03/20 14:42	8.2	7.75
123A6	2012/03/20 12:50	2012/03/20 14:43	8.39	7.78
123A7	2012/03/20 12:49	2012/03/20 14:44	7.89	7.71
123A8	2012/03/20 12:47	2012/03/20 14:46	7.92	7.67
123A9	2012/03/20 12:46	2012/03/20 14:47	7.93	7.9
123A10	2012/03/20 12:45	2012/03/20 14:48	7.94	7.63
123B1	2012/03/20 12:32	2012/03/20 14:51	8.46	7.62
123B2	2012/03/20 12:33	2012/03/20 14:52	8.06	7.5
123B3	2012/03/20 12:34	2012/03/20 14:53	8.2	7.52
123B4	2012/03/20 12:35	2012/03/20 14:54	8.32	7.59
123B5	2012/03/20 12:36	2012/03/20 14:54	8.35	7.43
123B6	2012/03/20 12:37	2012/03/20 14:55	8.09	7.29
123B7	2012/03/20 12:38	2012/03/20 14:56	8.15	7.42
123B8	2012/03/20 12:39	2012/03/20 14:57	8.06	7.41
123B9	2012/03/20 12:40	2012/03/20 14:57	8.13	7.3
123B10	2012/03/20 12:42	2012/03/20 14:58	8.13	7.42

Table C.1.5 (e)-(h) *– Abalone tank dissolved oxygen*

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/03/27 10:42	2012/03/27 10:55	9.63	8.8
122A2	2012/03/27 10:43	2012/03/27 10:56	9.14	8.71
122A3	2012/03/27 10:44	2012/03/27 10:57	8.89	8.68
122A4	2012/03/27 10:45	2012/03/27 10:58	8.91	8.61
122A5	2012/03/27 10:47	2012/03/27 10:59	8.94	9.11
122A6	2012/03/27 10:48	2012/03/27 11:01	8.98	8.57
122A7	2012/03/27 10:49	2012/03/27 11:01	9.34	8.72
122A8	2012/03/27 10:50	2012/03/27 11:02	9.12	8.75
122A9	2012/03/27 10:52	2012/03/27 11:03	9.22	8.82
122A10	2012/03/27 10:53	2012/03/27 11:04	8.77	8.81
122B1	2012/03/27 11:06	2012/03/27 11:20	9.3	8.97
122B2	2012/03/27 11:08	2012/03/27 11:21	9.41	8.92
122B3	2012/03/27 11:09	2012/03/27 11:22	9.25	9.17
122B4	2012/03/27 11:11	2012/03/27 11:23	9.29	9.11
122B5	2012/03/27 11:12	2012/03/27 11:23	9.22	8.99
122B6	2012/03/27 11:13	2012/03/27 11:24	9.17	8.93
122B7	2012/03/27 11:14	2012/03/27 11:25	9.24	8.96
122B8	2012/03/27 11:15	2012/03/27 11:26	9.27	8.96
122B9	2012/03/27 11:16	2012/03/27 11:27	9.23	8.96
122B10	2012/03/27 11:17	2012/03/27 11:28	9.48	8.96
123A1	2012/03/27 11:44	2012/03/27 11:56	7.56	8.31
123A2	2012/03/27 11:45	2012/03/27 11:57	7.45	8.37
123A3	2012/03/27 11:47	2012/03/27 11:57	7.7	8.32
123A4	2012/03/27 11:48	2012/03/27 11:58	7.91	8.36
123A5	2012/03/27 11:49	2012/03/27 11:59	8.02	8.39
123A6	2012/03/27 11:50	2012/03/27 12:01	8.04	8.46
123A7	2012/03/27 11:51	2012/03/27 12:02	8.2	8.5
123A8	2012/03/27 11:52	2012/03/27 12:03	8.5	8.43
123A9	2012/03/27 11:53	2012/03/27 12:04	8.43	8.66
123A10	2012/03/27 11:54	2012/03/27 12:04	8.45	8.42
123B1	2012/03/27 14:15	2012/03/27 14:29	8.48	9.22
123B2	2012/03/27 14:16	2012/03/27 14:30	8.34	8.95
123B3	2012/03/27 14:19	2012/03/27 14:30	8.25	8.93
123B4	2012/03/27 14:20	2012/03/27 14:31	8.64	8.92
123B5	2012/03/27 14:21	2012/03/27 14:32	8.94	8.88
123B6	2012/03/27 14:22	2012/03/27 14:52	8.78	7.35
123B7	2012/03/27 14:23	2012/03/27 14:53	8.76	7.47
123B8	2012/03/27 14:24	2012/03/27 14:53	8.76	7.61
123B9	2012/03/27 14:25	2012/03/27 14:54	8.78	7.76
123B10	2012/03/27 14:26	2012/03/27 14:55	8.69	7.94

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/04/03 11:12	2012/04/03 11:25	6.37	7.46
122A2	2012/04/03 11:13	2012/04/03 11:27	6.75	7.51
122A3	2012/04/03 11:14	2012/04/03 11:28	6.78	7.4
122A4	2012/04/03 11:15	2012/04/03 11:29	6.84	7.43
122A5	2012/04/03 11:16	2012/04/03 11:30	7.1	7.3
122A6	2012/04/03 11:17	2012/04/03 11:32	7.21	7.69
122A7	2012/04/03 11:18	2012/04/03 11:33	7.37	7.59
122A8	2012/04/03 11:20	2012/04/03 11:34	7.4	7.45
122A9	2012/04/03 11:21	2012/04/03 11:35	7.43	7.47
122A10	2012/04/03 11:22	2012/04/03 11:36	7.66	7.58
122B1	2012/04/03 12:08	2012/04/03 12:20	6.59	7.41
122B2	2012/04/03 12:09	2012/04/03 12:21	6.63	7.35
122B3	2012/04/03 12:11	2012/04/03 12:22	7.03	7.4
122B4	2012/04/03 12:13	2012/04/03 12:23	6.96	7.39
122B5	2012/04/03 12:13	2012/04/03 12:23	7.3	7.38
122B6	2012/04/03 12:14	2012/04/03 12:24	7.18	7.41
122B7	2012/04/03 12:15	2012/04/03 12:25	7.14	7.43
122B8	2012/04/03 12:16	2012/04/03 12:26	7.39	7.46
122B9	2012/04/03 12:17	2012/04/03 12:26	7.58	7.56
122B10	2012/04/03 12:18	2012/04/03 12:27	7.7	7.54
123A1	2012/04/03 14:49	2012/04/03 14:59	8.08	7.92
123A2	2012/04/03 14:50	2012/04/03 15:00	8.08	7.93
123A3	2012/04/03 14:51	2012/04/03 15:01	8.02	7.92
123A4	2012/04/03 14:52	2012/04/03 15:02	7.86	7.88
123A5	2012/04/03 14:53	2012/04/03 15:03	7.94	7.91
123A6	2012/04/03 14:54	2012/04/03 15:04	8.1	7.93
123A7	2012/04/03 14:55	2012/04/03 15:05	8.19	7.95
123A8	2012/04/03 14:56	2012/04/03 15:05	8.09	7.89
123A9	2012/04/03 14:57	2012/04/03 15:06	8.07	8.08
123A10	2012/04/03 14:57	2012/04/03 15:07	8.11	7.96
123B1	2012/04/03 15:27	2012/04/03 15:51	8.8	6.18
123B2	2012/04/03 15:28	2012/04/03 15:52	8.52	6.42
123B3	2012/04/03 15:29	2012/04/03 15:53	9.06	6.77
123B4	2012/04/03 15:30	2012/04/03 15:53	8.39	6.91
123B5	2012/04/03 15:31	2012/04/03 15:54	8.62	7.05
123B6	2012/04/03 15:32	2012/04/03 15:55	8.63	7.22
123B7	2012/04/03 15:33	2012/04/03 15:56	8.6	7.24
123B8	2012/04/03 15:34	2012/04/03 15:57	8.44	7.3
123B9	2012/04/03 15:35	2012/04/03 15:57	8.62	7.34
123B10	2012/04/03 15:36	2012/04/03 15:58	8.5	7.5

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/04/19 10:52	2012/04/19 11:16	9.25	7.63
122A2	2012/04/19 10:53	2012/04/19 11:17	8.73	7.62
122A3	2012/04/19 10:54	2012/04/19 11:17	8.68	7.52
122A4	2012/04/19 10:55	2012/04/19 11:18	8.5	7.52
122A5	2012/04/19 10:56	2012/04/19 11:19	8.5	7.4
122A6	2012/04/19 10:57	2012/04/19 11:20	8.51	7.95
122A7	2012/04/19 10:58	2012/04/19 11:21	8.83	7.63
122A8	2012/04/19 11:00	2012/04/19 11:22	8.54	7.45
122A9	2012/04/19 11:01	2012/04/19 11:22	8.45	7.49
122A10	2012/04/19 11:02	2012/04/19 11:24	8.74	7.48
122B1	2012/04/19 11:04	2012/04/19 11:25	8.67	7.67
122B2	2012/04/19 11:05	2012/04/19 11:26	9.01	7.37
122B3	2012/04/19 11:06	2012/04/19 11:27	8.62	7.48
122B4	2012/04/19 11:07	2012/04/19 11:28	8.46	7.65
122B5	2012/04/19 11:08	2012/04/19 11:28	8.87	7.48
122B6	2012/04/19 11:09	2012/04/19 11:29	8.5	7.36
122B7	2012/04/19 11:10	2012/04/19 11:29	8.58	7.31
122B8	2012/04/19 11:11	2012/04/19 11:30	8.73	7.45
122B9	2012/04/19 11:12	2012/04/19 11:31	8.4	7.88
122B10	2012/04/19 11:13	2012/04/19 11:31	8.8	7.54
123A1	2012/04/19 11:41	2012/04/19 12:10	8.52	7.54
123A2	2012/04/19 11:41	2012/04/19 12:11	8.92	7.68
123A3	2012/04/19 11:42	2012/04/19 12:11	8.31	7.43
123A4	2012/04/19 11:43	2012/04/19 12:12	8.43	7.34
123A5	2012/04/19 11:44	2012/04/19 12:13	8.6	7.55
123A6	2012/04/19 11:45	2012/04/19 12:13	8.83	7.69
123A7	2012/04/19 11:46	2012/04/19 12:14	8.36	7.69
123A8	2012/04/19 11:47	2012/04/19 12:23	8.7	7.65
123A9	2012/04/19 11:48	2012/04/19 12:23	8.41	8.11
123A10	2012/04/19 11:49	2012/04/19 12:24	8.45	7.64
123B1	2012/04/19 11:53	2012/04/19 12:25	9.17	7.79
123B2	2012/04/19 11:54	2012/04/19 12:26	8.46	7.36
123B3	2012/04/19 11:55	2012/04/19 12:26	8.24	7.48
123B4	2012/04/19 11:56	2012/04/19 12:27	8.48	7.58
123B5	2012/04/19 11:57	2012/04/19 12:28	8.52	7.5
123B6	2012/04/19 11:58	2012/04/19 12:28	8.34	7.45
123B7	2012/04/19 11:59	2012/04/19 12:29	8.38	7.46
123B8	2012/04/19 11:59	2012/04/19 12:29	8.37	7.49
123B9	2012/04/19 12:00	2012/04/19 12:30	8.23	7.59
123B10	2012/04/19 12:01	2012/04/19 12:31	8.74	7.96

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/04/26 11:00	2012/04/26 12:57	9.48	8.66
122A2	2012/04/26 11:01	2012/04/26 12:57	9.65	8.69
122A3	2012/04/26 11:02	2012/04/26 12:59	9.35	8.65
122A4	2012/04/26 11:04	2012/04/26 12:59	9.54	8.4
122A5	2012/04/26 11:05	2012/04/26 13:00	9.34	8.38
122A6	2012/04/26 11:06	2012/04/26 13:01	9.49	8.77
122A7	2012/04/26 11:07	2012/04/26 13:02	9.62	8.6
122A8	2012/04/26 11:08	2012/04/26 13:03	9.08	8.5
122A9	2012/04/26 11:10	2012/04/26 13:04	9.44	8.51
122A10	2012/04/26 11:11	2012/04/26 13:04	9.38	8.51
122B1	2012/04/26 11:25	2012/04/26 13:06	9.46	8.45
122B2	2012/04/26 11:26	2012/04/26 13:07	9.5	8.36
122B3	2012/04/26 11:28	2012/04/26 13:08	9.44	8.42
122B4	2012/04/26 11:29	2012/04/26 13:09	9.28	8.51
122B5	2012/04/26 11:31	2012/04/26 13:10	9.41	8.37
122B6	2012/04/26 11:32	2012/04/26 13:10	9.41	8.37
122B7	2012/04/26 11:33	2012/04/26 13:11	9.1	8.43
122B8	2012/04/26 11:34	2012/04/26 13:12	9.47	8.5
122B9	2012/04/26 11:35	2012/04/26 13:12	9.31	8.65
122B10	2012/04/26 11:36	2012/04/26 13:13	9.32	8.58
123A1	2012/04/26 11:41	2012/04/26 13:24	9.4	8.64
123A2	2012/04/26 11:42	2012/04/26 13:24	9.4	8.65
123A3	2012/04/26 11:43	2012/04/26 13:25	9.1	8.44
123A4	2012/04/26 11:44	2012/04/26 13:26	9.43	8.42
123A5	2012/04/26 11:46	2012/04/26 13:27	9.39	8.48
123A6	2012/04/26 11:47	2012/04/26 13:28	9.32	8.55
123A7	2012/04/26 11:48	2012/04/26 13:28	9.04	8.54
123A8	2012/04/26 11:49	2012/04/26 13:29	9.24	8.71
123A9	2012/04/26 11:50	2012/04/26 13:30	9.21	8.94
123A10	2012/04/26 11:51	2012/04/26 13:31	9.28	8.67
123B1	2012/04/26 11:54	2012/04/26 13:32	9.54	8.75
123B2	2012/04/26 11:55	2012/04/26 13:33	9.33	8.35
123B3	2012/04/26 11:56	2012/04/26 13:34	9.54	8.51
123B4	2012/04/26 11:57	2012/04/26 13:35	9.47	8.56
123B5	2012/04/26 11:59	2012/04/26 13:35	9.42	8.44
123B6	2012/04/26 12:00	2012/04/26 13:37	9.36	8.45
123B7	2012/04/26 12:01	2012/04/26 13:37	9.15	8.44
123B8	2012/04/26 12:02	2012/04/26 13:38	9.29	8.41
123B9	2012/04/26 12:02	2012/04/26 13:39	9.22	8.48
123B10	2012/04/26 12:03	2012/04/26 13:39	9.51	8.82

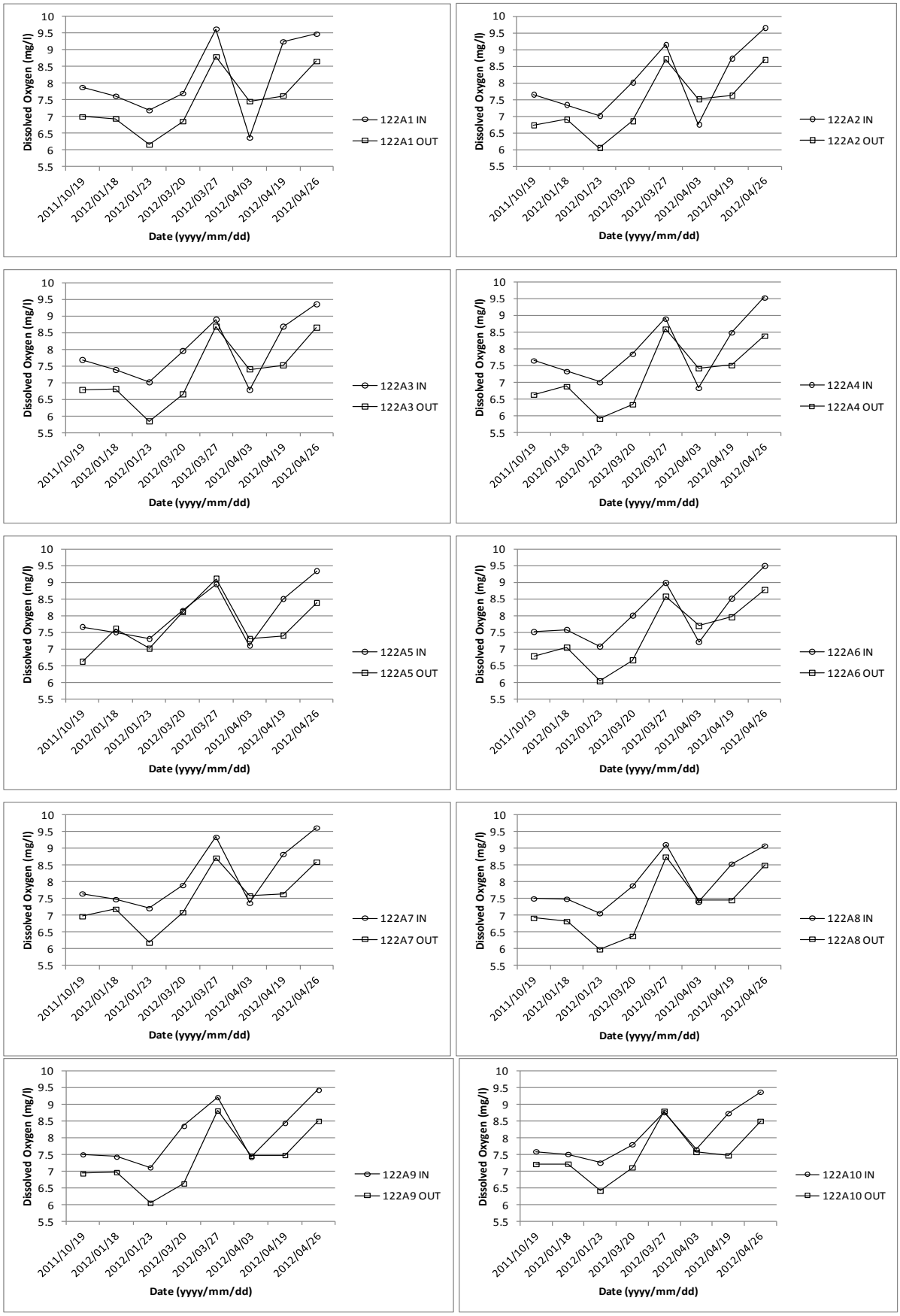


Figure C.1.5.1 *– Row 122A abalone tank dissolved oxygen*

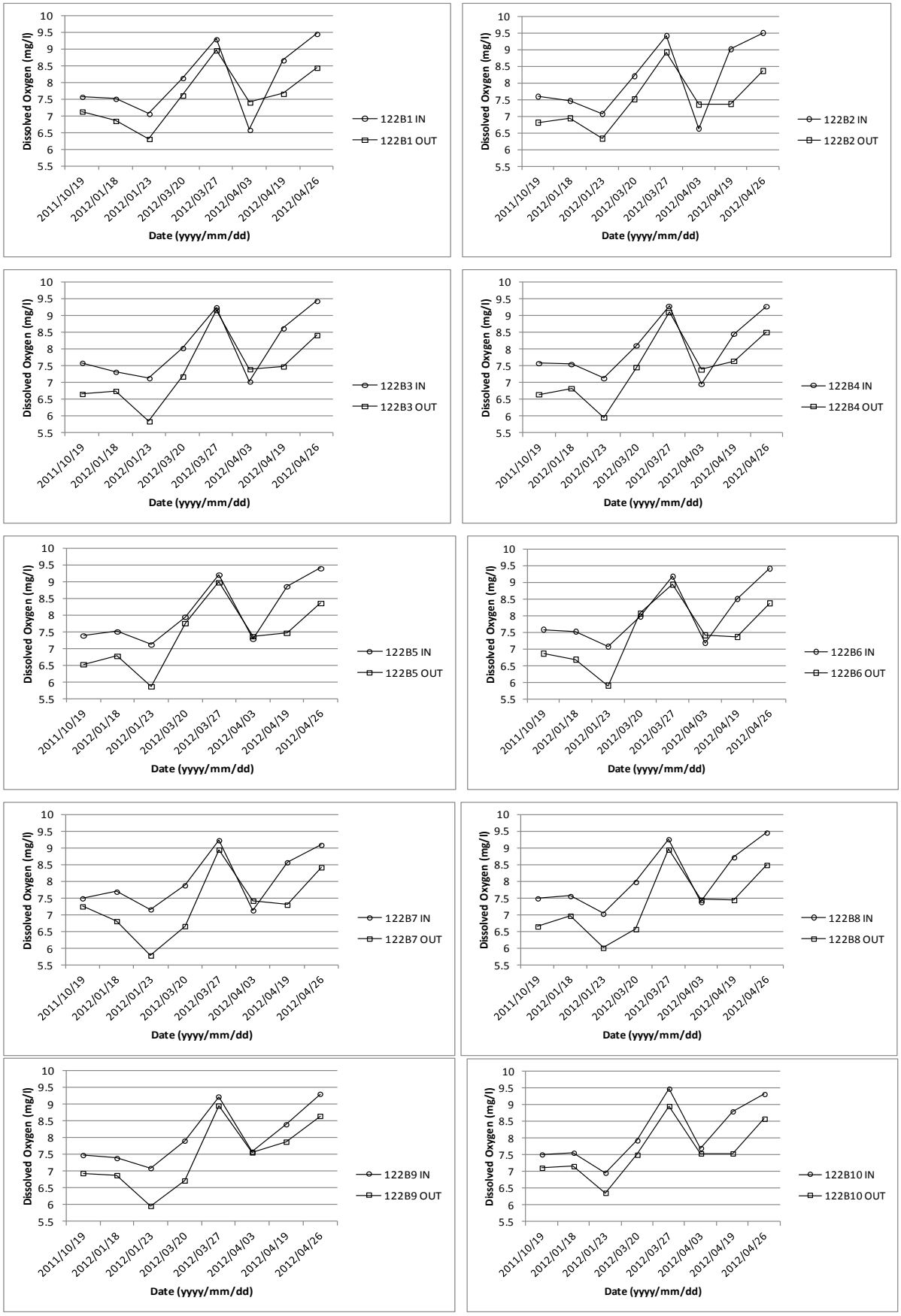


Figure C.1.5.2 *– Row 122B abalone tank dissolved oxygen*

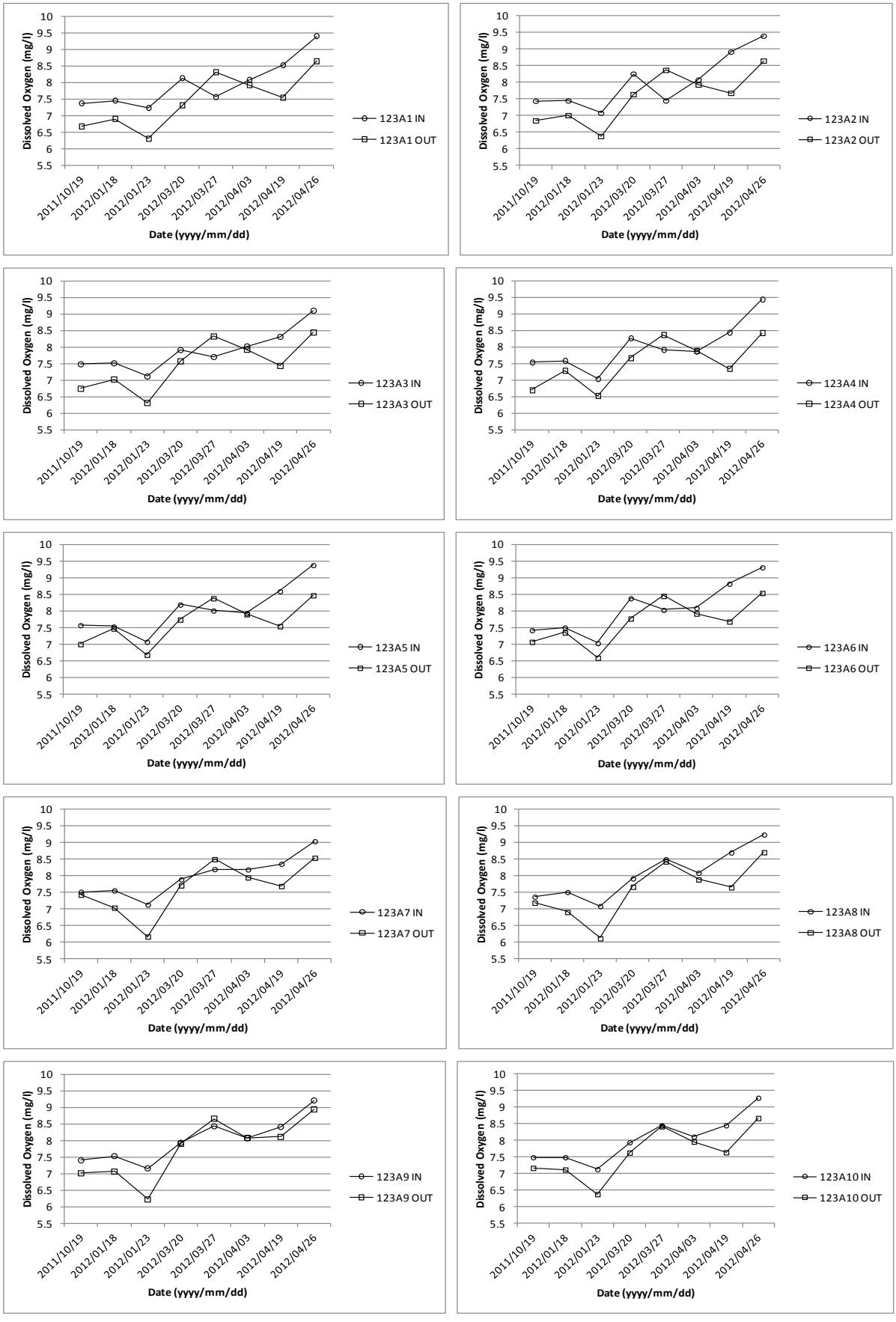


Figure C.1.5.3 *– Row 123A abalone tank dissolved oxygen*

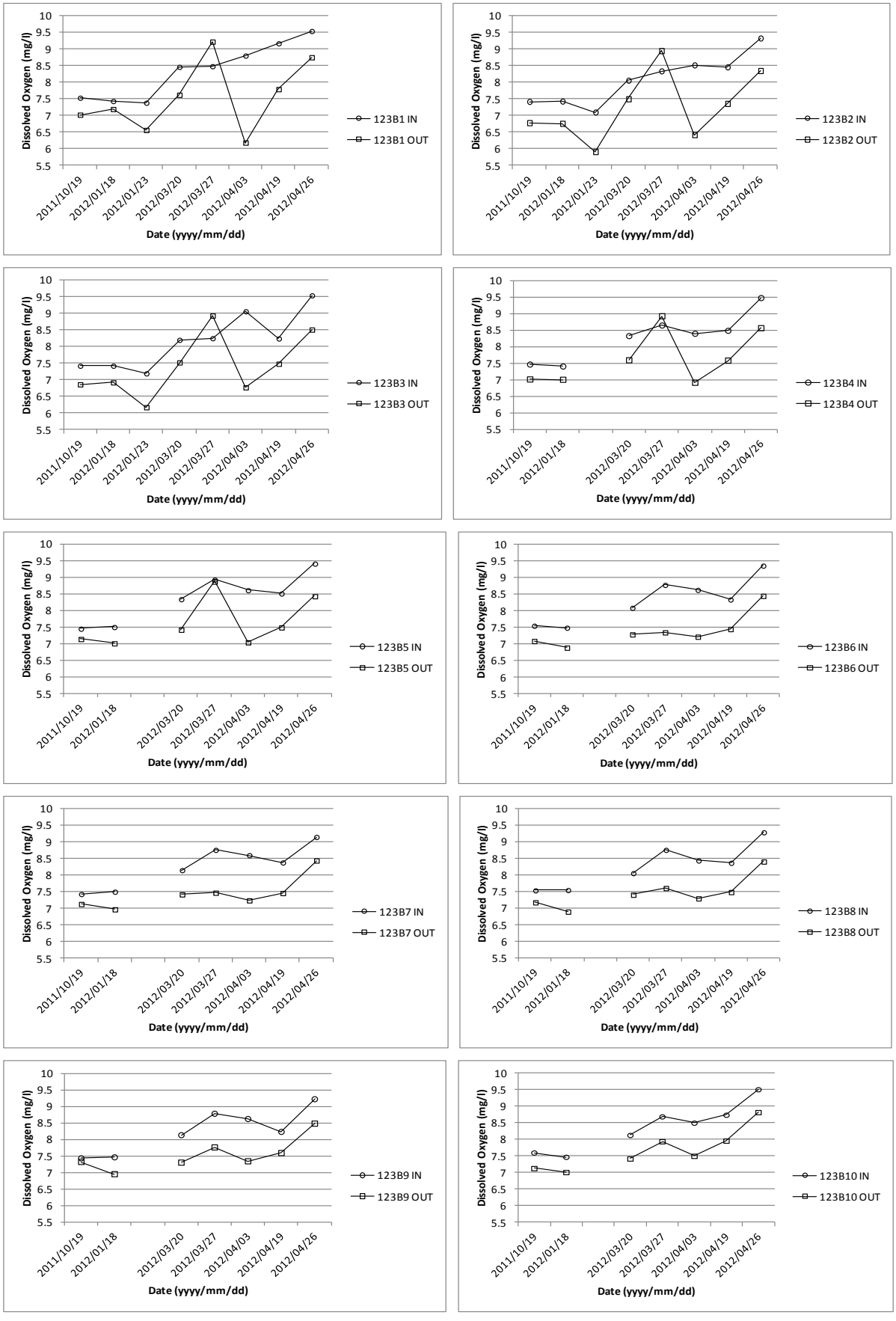


Figure C.1.5.4 *– Row 123B abalone tank dissolved oxygen*

C.1.6 pH

Table C.1.6 (a)-(d) – *Abalone tank pH*

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2011/10/19 09:26	2011/09/27 10:14	7.88	7
122A2	2011/10/19 09:29	2011/09/27 10:14	7.65	6.73
122A3	2011/10/19 09:32	2011/09/27 10:14	7.68	6.78
122A4	2011/10/19 09:35	2011/09/27 10:14	7.66	6.64
122A5	2011/10/19 09:38	2011/09/27 10:14	7.66	6.62
122A6	2011/10/19 09:41	2011/09/27 10:14	7.51	6.78
122A7	2011/10/19 09:45	2011/09/27 10:14	7.65	6.97
122A8	2011/10/19 09:48	2011/09/27 10:14	7.5	6.92
122A9	2011/10/19 09:52	2011/09/27 10:14	7.51	6.94
122A10	2011/10/19 09:55	2011/09/27 10:14	7.6	7.22
122B1	2011/10/19 10:02	2011/09/27 10:14	7.58	7.14
122B2	2011/10/19 10:04	2011/09/27 10:14	7.59	6.81
122B3	2011/10/19 10:08	2011/09/27 10:14	7.59	6.66
122B4	2011/10/19 10:11	2011/09/27 10:14	7.58	6.65
122B5	2011/10/19 10:15	2011/09/27 10:14	7.4	6.54
122B6	2011/10/19 10:20	2011/09/27 10:14	7.58	6.86
122B7	2011/10/19 10:23	2011/09/27 10:14	7.5	7.26
122B8	2011/10/19 10:26	2011/09/27 10:14	7.5	6.66
122B9	2011/10/19 10:30	2011/09/27 10:14	7.48	6.94
122B10	2011/10/19 10:32	2011/09/27 10:14	7.51	7.11
123A1	2011/10/19 11:45	2011/09/27 10:14	7.37	6.67
123A2	2011/10/19 11:48	2011/09/27 10:14	7.44	6.85
123A3	2011/10/19 11:52	2011/09/27 10:14	7.48	6.74
123A4	2011/10/19 11:55	2011/09/27 10:14	7.53	6.69
123A5	2011/10/19 11:59	2011/09/27 10:14	7.58	7.01
123A6	2011/10/19 12:02	2011/09/27 10:14	7.43	7.08
123A7	2011/10/19 12:05	2011/09/27 10:14	7.52	7.43
123A8	2011/10/19 12:13	2011/09/27 10:14	7.37	7.19
123A9	2011/10/19 12:15	2011/09/27 10:14	7.4	7.01
123A10	2011/10/19 12:18	2011/09/27 10:14	7.49	7.17
123B1	2011/10/19 12:21	2011/09/27 10:14	7.53	7.02
123B2	2011/10/19 12:23	2011/09/27 10:14	7.42	6.78
123B3	2011/10/19 12:26	2011/09/27 10:14	7.42	6.86
123B4	2011/10/19 12:28	2011/09/27 10:14	7.46	7.01
123B5	2011/10/19 12:30	2011/09/27 10:14	7.46	7.15
123B6	2011/10/19 12:32	2011/09/27 10:14	7.55	7.09
123B7	2011/10/19 12:34	2011/09/27 10:14	7.43	7.13
123B8	2011/10/19 12:37	2011/09/27 10:14	7.54	7.18
123B9	2011/10/19 12:40	2011/09/27 10:14	7.43	7.32
123B10	2011/10/19 12:42	2011/09/27 10:14	7.6	7.13

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/01/18 09:37	2012/01/18 09:39	7.62	6.94
122A2	2012/01/18 09:40	2012/01/18 09:41	7.34	6.9
122A3	2012/01/18 09:42	2012/01/18 09:43	7.38	6.81
122A4	2012/01/18 09:44	2012/01/18 09:45	7.34	6.89
122A5	2012/01/18 09:46	2012/01/18 09:47	7.5	7.61
122A6	2012/01/18 09:49	2012/01/18 09:50	7.57	7.04
122A7	2012/01/18 09:51	2012/01/18 09:51	7.48	7.19
122A8	2012/01/18 09:54	2012/01/18 09:55	7.49	6.82
122A9	2012/01/18 09:59	2012/01/18 10:00	7.44	6.98
122A10	2012/01/18 10:02	2012/01/18 10:03	7.52	7.23
122B1	2012/01/18 10:23	2012/01/18 10:25	7.52	6.86
122B2	2012/01/18 10:26	2012/01/18 10:27	7.46	6.94
122B3	2012/01/18 10:28	2012/01/18 10:30	7.32	6.75
122B4	2012/01/18 10:31	2012/01/18 10:32	7.55	6.83
122B5	2012/01/18 10:33	2012/01/18 10:35	7.52	6.79
122B6	2012/01/18 10:36	2012/01/18 10:38	7.52	6.68
122B7	2012/01/18 10:40	2012/01/18 10:41	7.7	6.82
122B8	2012/01/18 10:43	2012/01/18 10:44	7.57	6.98
122B9	2012/01/18 10:45	2012/01/18 10:47	7.39	6.88
122B10	2012/01/18 10:48	2012/01/18 10:49	7.56	7.16
123A1	2012/01/18 10:59	2012/01/18 11:00	7.45	6.9
123A2	2012/01/18 11:02	2012/01/18 11:03	7.45	7.01
123A3	2012/01/18 11:05	2012/01/18 11:07	7.51	7.02
123A4	2012/01/18 11:08	2012/01/18 11:09	7.58	7.28
123A5	2012/01/18 11:11	2012/01/18 11:12	7.54	7.48
123A6	2012/01/18 11:13	2012/01/18 11:15	7.51	7.36
123A7	2012/01/18 11:16	2012/01/18 11:17	7.56	7.04
123A8	2012/01/18 11:18	2012/01/18 11:20	7.51	6.91
123A9	2012/01/18 11:21	2012/01/18 11:22	7.53	7.06
123A10	2012/01/18 11:24	2012/01/18 11:25	7.49	7.12
123B1	2012/01/18 11:35	2012/01/18 11:36	7.43	7.19
123B2	2012/01/18 11:38	2012/01/18 11:39	7.43	6.76
123B3	2012/01/18 11:40	2012/01/18 11:41	7.42	6.92
123B4	2012/01/18 11:42	2012/01/18 11:43	7.4	7
123B5	2012/01/18 11:45	2012/01/18 11:46	7.51	7.02
123B6	2012/01/18 11:47	2012/01/18 11:49	7.49	6.89
123B7	2012/01/18 11:50	2012/01/18 11:51	7.5	6.97
123B8	2012/01/18 11:52	2012/01/18 11:53	7.55	6.9
123B9	2012/01/18 11:55	2012/01/18 11:56	7.46	6.95
123B10	2012/01/18 11:58	2012/01/18 11:59	7.47	7.01

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/01/23 12:23	2012/01/23 12:25	7.19	6.16
122A2	2012/01/23 12:26	2012/01/23 12:28	7.01	6.05
122A3	2012/01/23 12:29	2012/01/23 12:31	7.01	5.84
122A4	2012/01/23 12:37	2012/01/23 12:39	7.01	5.92
122A5	2012/01/23 12:43	2012/01/23 12:46	7.3	7.01
122A6	2012/01/23 12:48	2012/01/23 12:49	7.07	6.03
122A7	2012/01/23 12:51	2012/01/23 12:52	7.21	6.18
122A8	2012/01/23 12:54	2012/01/23 12:55	7.06	5.98
122A9	2012/01/23 12:57	2012/01/23 12:59	7.12	6.06
122A10	2012/01/23 13:01	2012/01/23 13:02	7.26	6.42
122B1	2012/01/23 13:06	2012/01/23 13:07	7.07	6.32
122B2	2012/01/23 13:08	2012/01/23 13:10	7.07	6.33
122B3	2012/01/23 13:12	2012/01/23 13:13	7.13	5.84
122B4	2012/01/23 13:15	2012/01/23 13:16	7.13	5.96
122B5	2012/01/23 13:18	2012/01/23 13:19	7.13	5.88
122B6	2012/01/23 13:21	2012/01/23 13:22	7.07	5.9
122B7	2012/01/23 13:23	2012/01/23 13:25	7.17	5.79
122B8	2012/01/23 13:27	2012/01/23 13:28	7.04	6.02
122B9	2012/01/23 13:30	2012/01/23 13:31	7.09	5.96
122B10	2012/01/23 13:32	2012/01/23 13:34	6.96	6.36
123A1	2012/01/23 14:07	2012/01/23 14:08	7.23	6.3
123A2	2012/01/23 14:10	2012/01/23 14:12	7.08	6.38
123A3	2012/01/23 14:14	2012/01/23 14:15	7.11	6.31
123A4	2012/01/23 14:17	2012/01/23 14:23	7.03	6.52
123A5	2012/01/23 14:24	2012/01/23 14:26	7.08	6.69
123A6	2012/01/23 14:30	2012/01/23 14:32	7.04	6.6
123A7	2012/01/23 14:35	2012/01/23 14:37	7.13	6.17
123A8	2012/01/23 14:38	2012/01/23 14:40	7.09	6.12
123A9	2012/01/23 14:43	2012/01/23 14:44	7.16	6.22
123A10	2012/01/23 14:46	2012/01/23 14:47	7.13	6.38
123B1	2012/01/23 14:55	2012/01/23 14:56	7.38	6.56
123B2	2012/01/23 15:00	2012/01/23 15:02	7.1	5.91
123B3	2012/01/23 15:03	2012/01/23 15:05	7.19	6.17
123B4	2012/01/23 15:18	2012/01/23 16:11	7.02	7.59
123B5	2012/01/23 16:13	2012/01/23 16:15	8.59	7.44
123B6	2012/01/23 16:17	2012/01/23 16:19	8.59	7.64
123B7	2012/01/23 16:21	2012/01/23 16:22	7.08	7.69
123B8	2012/01/23 16:26	2012/01/23 16:27	6.92	6.19
123B9	2012/01/23 16:36	2012/01/23 16:38	8.53	7.48
123B10	2012/01/23 16:39	2012/01/23 16:40	8.65	7.62

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/03/20 11:40	2012/03/20 14:21	7.7	6.86
122A2	2012/03/20 11:42	2012/03/20 14:22	8.01	6.85
122A3	2012/03/20 11:44	2012/03/20 14:24	7.95	6.65
122A4	2012/03/20 11:46	2012/03/20 14:26	7.86	6.35
122A5	2012/03/20 11:49	2012/03/20 14:27	8.14	8.11
122A6	2012/03/20 11:50	2012/03/20 14:28	8	6.66
122A7	2012/03/20 11:53	2012/03/20 14:30	7.9	7.09
122A8	2012/03/20 11:55	2012/03/20 14:31	7.89	6.38
122A9	2012/03/20 11:57	2012/03/20 14:31	8.36	6.64
122A10	2012/03/20 11:59	2012/03/20 14:32	7.81	7.12
122B1	2012/03/20 12:11	2012/03/20 15:08	8.14	7.62
122B2	2012/03/20 12:13	2012/03/20 15:09	8.2	7.51
122B3	2012/03/20 12:14	2012/03/20 15:10	8.03	7.18
122B4	2012/03/20 12:15	2012/03/20 15:11	8.11	7.46
122B5	2012/03/20 12:17	2012/03/20 15:12	7.96	7.77
122B6	2012/03/20 12:18	2012/03/20 15:13	7.97	8.06
122B7	2012/03/20 12:19	2012/03/20 15:13	7.89	6.67
122B8	2012/03/20 12:21	2012/03/20 15:14	7.99	6.58
122B9	2012/03/20 12:22	2012/03/20 15:15	7.91	6.72
122B10	2012/03/20 12:26	2012/03/20 15:16	7.93	7.5
123A1	2012/03/20 12:55	2012/03/20 14:37	8.13	7.31
123A2	2012/03/20 12:54	2012/03/20 14:38	8.26	7.64
123A3	2012/03/20 12:53	2012/03/20 14:39	7.91	7.57
123A4	2012/03/20 12:52	2012/03/20 14:41	8.26	7.66
123A5	2012/03/20 12:51	2012/03/20 14:42	8.2	7.75
123A6	2012/03/20 12:50	2012/03/20 14:43	8.39	7.78
123A7	2012/03/20 12:49	2012/03/20 14:44	7.89	7.71
123A8	2012/03/20 12:47	2012/03/20 14:46	7.92	7.67
123A9	2012/03/20 12:46	2012/03/20 14:47	7.93	7.9
123A10	2012/03/20 12:45	2012/03/20 14:48	7.94	7.63
123B1	2012/03/20 12:32	2012/03/20 14:51	8.46	7.62
123B2	2012/03/20 12:33	2012/03/20 14:52	8.06	7.5
123B3	2012/03/20 12:34	2012/03/20 14:53	8.2	7.52
123B4	2012/03/20 12:35	2012/03/20 14:54	8.32	7.59
123B5	2012/03/20 12:36	2012/03/20 14:54	8.35	7.43
123B6	2012/03/20 12:37	2012/03/20 14:55	8.09	7.29
123B7	2012/03/20 12:38	2012/03/20 14:56	8.15	7.42
123B8	2012/03/20 12:39	2012/03/20 14:57	8.06	7.41
123B9	2012/03/20 12:40	2012/03/20 14:57	8.13	7.3
123B10	2012/03/20 12:42	2012/03/20 14:58	8.13	7.42

Table C.1.6 (e)-(h) – *Abalone tank pH*

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/03/27 10:42	2012/03/27 10:55	9.63	8.8
122A2	2012/03/27 10:43	2012/03/27 10:56	9.14	8.71
122A3	2012/03/27 10:44	2012/03/27 10:57	8.89	8.68
122A4	2012/03/27 10:45	2012/03/27 10:58	8.91	8.61
122A5	2012/03/27 10:47	2012/03/27 10:59	8.94	9.11
122A6	2012/03/27 10:48	2012/03/27 11:01	8.98	8.57
122A7	2012/03/27 10:49	2012/03/27 11:01	9.34	8.72
122A8	2012/03/27 10:50	2012/03/27 11:02	9.12	8.75
122A9	2012/03/27 10:52	2012/03/27 11:03	9.22	8.82
122A10	2012/03/27 10:53	2012/03/27 11:04	8.77	8.81
122B1	2012/03/27 11:06	2012/03/27 11:20	9.3	8.97
122B2	2012/03/27 11:08	2012/03/27 11:21	9.41	8.92
122B3	2012/03/27 11:09	2012/03/27 11:22	9.25	9.17
122B4	2012/03/27 11:11	2012/03/27 11:23	9.29	9.11
122B5	2012/03/27 11:12	2012/03/27 11:23	9.22	8.99
122B6	2012/03/27 11:13	2012/03/27 11:24	9.17	8.93
122B7	2012/03/27 11:14	2012/03/27 11:25	9.24	8.96
122B8	2012/03/27 11:15	2012/03/27 11:26	9.27	8.96
122B9	2012/03/27 11:16	2012/03/27 11:27	9.23	8.96
122B10	2012/03/27 11:17	2012/03/27 11:28	9.48	8.96
123A1	2012/03/27 11:44	2012/03/27 11:56	7.56	8.31
123A2	2012/03/27 11:45	2012/03/27 11:57	7.45	8.37
123A3	2012/03/27 11:47	2012/03/27 11:57	7.7	8.32
123A4	2012/03/27 11:48	2012/03/27 11:58	7.91	8.36
123A5	2012/03/27 11:49	2012/03/27 11:59	8.02	8.39
123A6	2012/03/27 11:50	2012/03/27 12:01	8.04	8.46
123A7	2012/03/27 11:51	2012/03/27 12:02	8.2	8.5
123A8	2012/03/27 11:52	2012/03/27 12:03	8.5	8.43
123A9	2012/03/27 11:53	2012/03/27 12:04	8.43	8.66
123A10	2012/03/27 11:54	2012/03/27 12:04	8.45	8.42
123B1	2012/03/27 14:15	2012/03/27 14:29	8.48	9.22
123B2	2012/03/27 14:16	2012/03/27 14:30	8.34	8.95
123B3	2012/03/27 14:19	2012/03/27 14:30	8.25	8.93
123B4	2012/03/27 14:20	2012/03/27 14:31	8.64	8.92
123B5	2012/03/27 14:21	2012/03/27 14:32	8.94	8.88
123B6	2012/03/27 14:22	2012/03/27 14:52	8.78	7.35
123B7	2012/03/27 14:23	2012/03/27 14:53	8.76	7.47
123B8	2012/03/27 14:24	2012/03/27 14:53	8.76	7.61
123B9	2012/03/27 14:25	2012/03/27 14:54	8.78	7.76
123B10	2012/03/27 14:26	2012/03/27 14:55	8.69	7.94

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/04/03 11:12	2012/04/03 11:25	6.37	7.46
122A2	2012/04/03 11:13	2012/04/03 11:27	6.75	7.51
122A3	2012/04/03 11:14	2012/04/03 11:28	6.78	7.4
122A4	2012/04/03 11:15	2012/04/03 11:29	6.84	7.43
122A5	2012/04/03 11:16	2012/04/03 11:30	7.1	7.3
122A6	2012/04/03 11:17	2012/04/03 11:32	7.21	7.69
122A7	2012/04/03 11:18	2012/04/03 11:33	7.37	7.59
122A8	2012/04/03 11:20	2012/04/03 11:34	7.4	7.45
122A9	2012/04/03 11:21	2012/04/03 11:35	7.43	7.47
122A10	2012/04/03 11:22	2012/04/03 11:36	7.66	7.58
122B1	2012/04/03 12:08	2012/04/03 12:20	6.59	7.41
122B2	2012/04/03 12:09	2012/04/03 12:21	6.63	7.35
122B3	2012/04/03 12:11	2012/04/03 12:22	7.03	7.4
122B4	2012/04/03 12:13	2012/04/03 12:23	6.96	7.39
122B5	2012/04/03 12:13	2012/04/03 12:23	7.3	7.38
122B6	2012/04/03 12:14	2012/04/03 12:24	7.18	7.41
122B7	2012/04/03 12:15	2012/04/03 12:25	7.14	7.43
122B8	2012/04/03 12:16	2012/04/03 12:26	7.39	7.46
122B9	2012/04/03 12:17	2012/04/03 12:26	7.58	7.56
122B10	2012/04/03 12:18	2012/04/03 12:27	7.7	7.54
123A1	2012/04/03 14:49	2012/04/03 14:59	8.08	7.92
123A2	2012/04/03 14:50	2012/04/03 15:00	8.08	7.93
123A3	2012/04/03 14:51	2012/04/03 15:01	8.02	7.92
123A4	2012/04/03 14:52	2012/04/03 15:02	7.86	7.88
123A5	2012/04/03 14:53	2012/04/03 15:03	7.94	7.91
123A6	2012/04/03 14:54	2012/04/03 15:04	8.1	7.93
123A7	2012/04/03 14:55	2012/04/03 15:05	8.19	7.95
123A8	2012/04/03 14:56	2012/04/03 15:05	8.09	7.89
123A9	2012/04/03 14:57	2012/04/03 15:06	8.07	8.08
123A10	2012/04/03 14:57	2012/04/03 15:07	8.11	7.96
123B1	2012/04/03 15:27	2012/04/03 15:51	8.8	6.18
123B2	2012/04/03 15:28	2012/04/03 15:52	8.52	6.42
123B3	2012/04/03 15:29	2012/04/03 15:53	9.06	6.77
123B4	2012/04/03 15:30	2012/04/03 15:53	8.39	6.91
123B5	2012/04/03 15:31	2012/04/03 15:54	8.62	7.05
123B6	2012/04/03 15:32	2012/04/03 15:55	8.63	7.22
123B7	2012/04/03 15:33	2012/04/03 15:56	8.6	7.24
123B8	2012/04/03 15:34	2012/04/03 15:57	8.44	7.3
123B9	2012/04/03 15:35	2012/04/03 15:57	8.62	7.34
123B10	2012/04/03 15:36	2012/04/03 15:58	8.5	7.5

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/04/19 10:52	2012/04/19 11:16	9.25	7.63
122A2	2012/04/19 10:53	2012/04/19 11:17	8.73	7.62
122A3	2012/04/19 10:54	2012/04/19 11:17	8.68	7.52
122A4	2012/04/19 10:55	2012/04/19 11:18	8.5	7.52
122A5	2012/04/19 10:56	2012/04/19 11:19	8.5	7.4
122A6	2012/04/19 10:57	2012/04/19 11:20	8.51	7.95
122A7	2012/04/19 10:58	2012/04/19 11:21	8.83	7.63
122A8	2012/04/19 11:00	2012/04/19 11:22	8.54	7.45
122A9	2012/04/19 11:01	2012/04/19 11:22	8.45	7.49
122A10	2012/04/19 11:02	2012/04/19 11:24	8.74	7.48
122B1	2012/04/19 11:04	2012/04/19 11:25	8.67	7.67
122B2	2012/04/19 11:05	2012/04/19 11:26	9.01	7.37
122B3	2012/04/19 11:06	2012/04/19 11:27	8.62	7.48
122B4	2012/04/19 11:07	2012/04/19 11:28	8.46	7.65
122B5	2012/04/19 11:08	2012/04/19 11:28	8.87	7.48
122B6	2012/04/19 11:09	2012/04/19 11:29	8.5	7.36
122B7	2012/04/19 11:10	2012/04/19 11:29	8.58	7.31
122B8	2012/04/19 11:11	2012/04/19 11:30	8.73	7.45
122B9	2012/04/19 11:12	2012/04/19 11:31	8.4	7.88
122B10	2012/04/19 11:13	2012/04/19 11:31	8.8	7.54
123A1	2012/04/19 11:41	2012/04/19 12:10	8.52	7.54
123A2	2012/04/19 11:41	2012/04/19 12:11	8.92	7.68
123A3	2012/04/19 11:42	2012/04/19 12:11	8.31	7.43
123A4	2012/04/19 11:43	2012/04/19 12:12	8.43	7.34
123A5	2012/04/19 11:44	2012/04/19 12:13	8.6	7.55
123A6	2012/04/19 11:45	2012/04/19 12:13	8.83	7.69
123A7	2012/04/19 11:46	2012/04/19 12:14	8.36	7.69
123A8	2012/04/19 11:47	2012/04/19 12:23	8.7	7.65
123A9	2012/04/19 11:48	2012/04/19 12:23	8.41	8.11
123A10	2012/04/19 11:49	2012/04/19 12:24	8.45	7.64
123B1	2012/04/19 11:53	2012/04/19 12:25	9.17	7.79
123B2	2012/04/19 11:54	2012/04/19 12:26	8.46	7.36
123B3	2012/04/19 11:55	2012/04/19 12:26	8.24	7.48
123B4	2012/04/19 11:56	2012/04/19 12:27	8.48	7.58
123B5	2012/04/19 11:57	2012/04/19 12:28	8.52	7.5
123B6	2012/04/19 11:58	2012/04/19 12:28	8.34	7.45
123B7	2012/04/19 11:59	2012/04/19 12:29	8.38	7.46
123B8	2012/04/19 11:59	2012/04/19 12:29	8.37	7.49
123B9	2012/04/19 12:00	2012/04/19 12:30	8.23	7.59
123B10	2012/04/19 12:01	2012/04/19 12:31	8.74	7.96

Site	Timestamp		Dissolved Oxygen (mg/l)	
	IN	OUT	IN	OUT
122A1	2012/04/26 11:00	2012/04/26 12:57	9.48	8.66
122A2	2012/04/26 11:01	2012/04/26 12:57	9.65	8.69
122A3	2012/04/26 11:02	2012/04/26 12:59	9.35	8.65
122A4	2012/04/26 11:04	2012/04/26 12:59	9.54	8.4
122A5	2012/04/26 11:05	2012/04/26 13:00	9.34	8.38
122A6	2012/04/26 11:06	2012/04/26 13:01	9.49	8.77
122A7	2012/04/26 11:07	2012/04/26 13:02	9.62	8.6
122A8	2012/04/26 11:08	2012/04/26 13:03	9.08	8.5
122A9	2012/04/26 11:10	2012/04/26 13:04	9.44	8.51
122A10	2012/04/26 11:11	2012/04/26 13:04	9.38	8.51
122B1	2012/04/26 11:25	2012/04/26 13:06	9.46	8.45
122B2	2012/04/26 11:26	2012/04/26 13:07	9.5	8.36
122B3	2012/04/26 11:28	2012/04/26 13:08	9.44	8.42
122B4	2012/04/26 11:29	2012/04/26 13:09	9.28	8.51
122B5	2012/04/26 11:31	2012/04/26 13:10	9.41	8.37
122B6	2012/04/26 11:32	2012/04/26 13:10	9.41	8.37
122B7	2012/04/26 11:33	2012/04/26 13:11	9.1	8.43
122B8	2012/04/26 11:34	2012/04/26 13:12	9.47	8.5
122B9	2012/04/26 11:35	2012/04/26 13:12	9.31	8.65
122B10	2012/04/26 11:36	2012/04/26 13:13	9.32	8.58
123A1	2012/04/26 11:41	2012/04/26 13:24	9.4	8.64
123A2	2012/04/26 11:42	2012/04/26 13:24	9.4	8.65
123A3	2012/04/26 11:43	2012/04/26 13:25	9.1	8.44
123A4	2012/04/26 11:44	2012/04/26 13:26	9.43	8.42
123A5	2012/04/26 11:46	2012/04/26 13:27	9.39	8.48
123A6	2012/04/26 11:47	2012/04/26 13:28	9.32	8.55
123A7	2012/04/26 11:48	2012/04/26 13:28	9.04	8.54
123A8	2012/04/26 11:49	2012/04/26 13:29	9.24	8.71
123A9	2012/04/26 11:50	2012/04/26 13:30	9.21	8.94
123A10	2012/04/26 11:51	2012/04/26 13:31	9.28	8.67
123B1	2012/04/26 11:54	2012/04/26 13:32	9.54	8.75
123B2	2012/04/26 11:55	2012/04/26 13:33	9.33	8.35
123B3	2012/04/26 11:56	2012/04/26 13:34	9.54	8.51
123B4	2012/04/26 11:57	2012/04/26 13:35	9.47	8.56
123B5	2012/04/26 11:59	2012/04/26 13:35	9.42	8.44
123B6	2012/04/26 12:00	2012/04/26 13:37	9.36	8.45
123B7	2012/04/26 12:01	2012/04/26 13:37	9.15	8.44
123B8	2012/04/26 12:02	2012/04/26 13:38	9.29	8.41
123B9	2012/04/26 12:02	2012/04/26 13:39	9.22	8.48
123B10	2012/04/26 12:03	2012/04/26 13:39	9.51	8.82

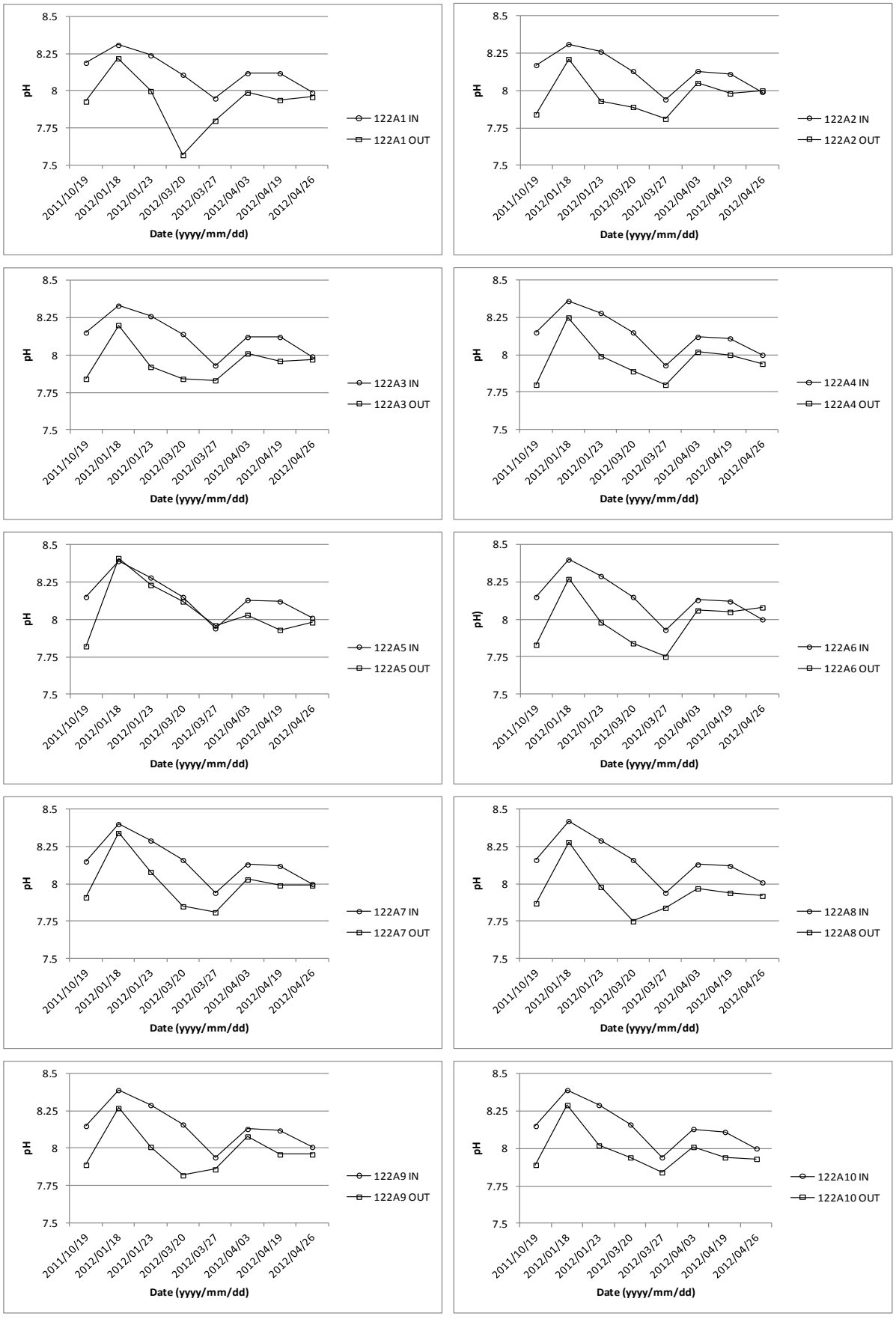


Figure C.1.6.1 *– Row 122A abalone tank pH*

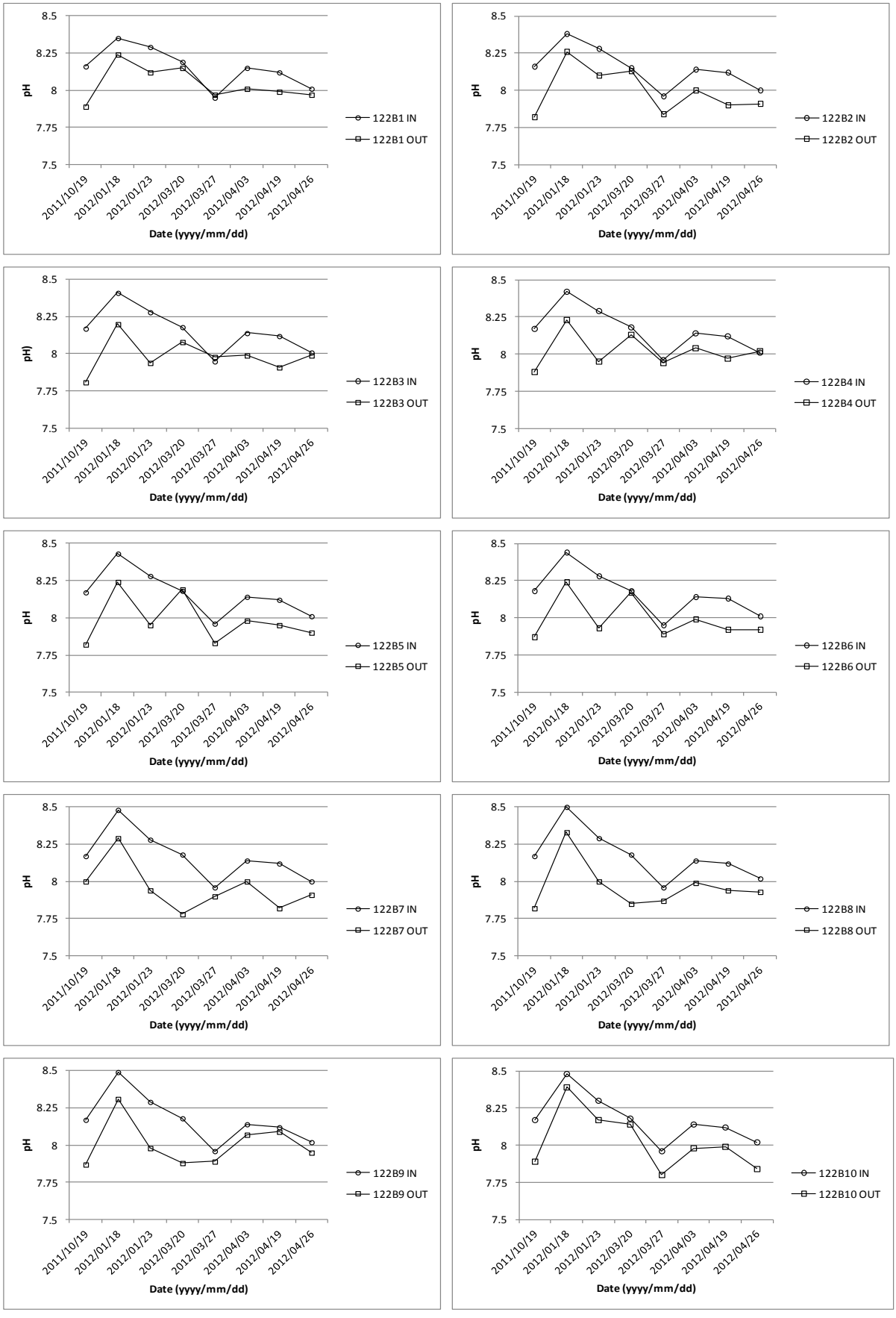


Figure C.1.6.2 *– Row 122B abalone tank pH*

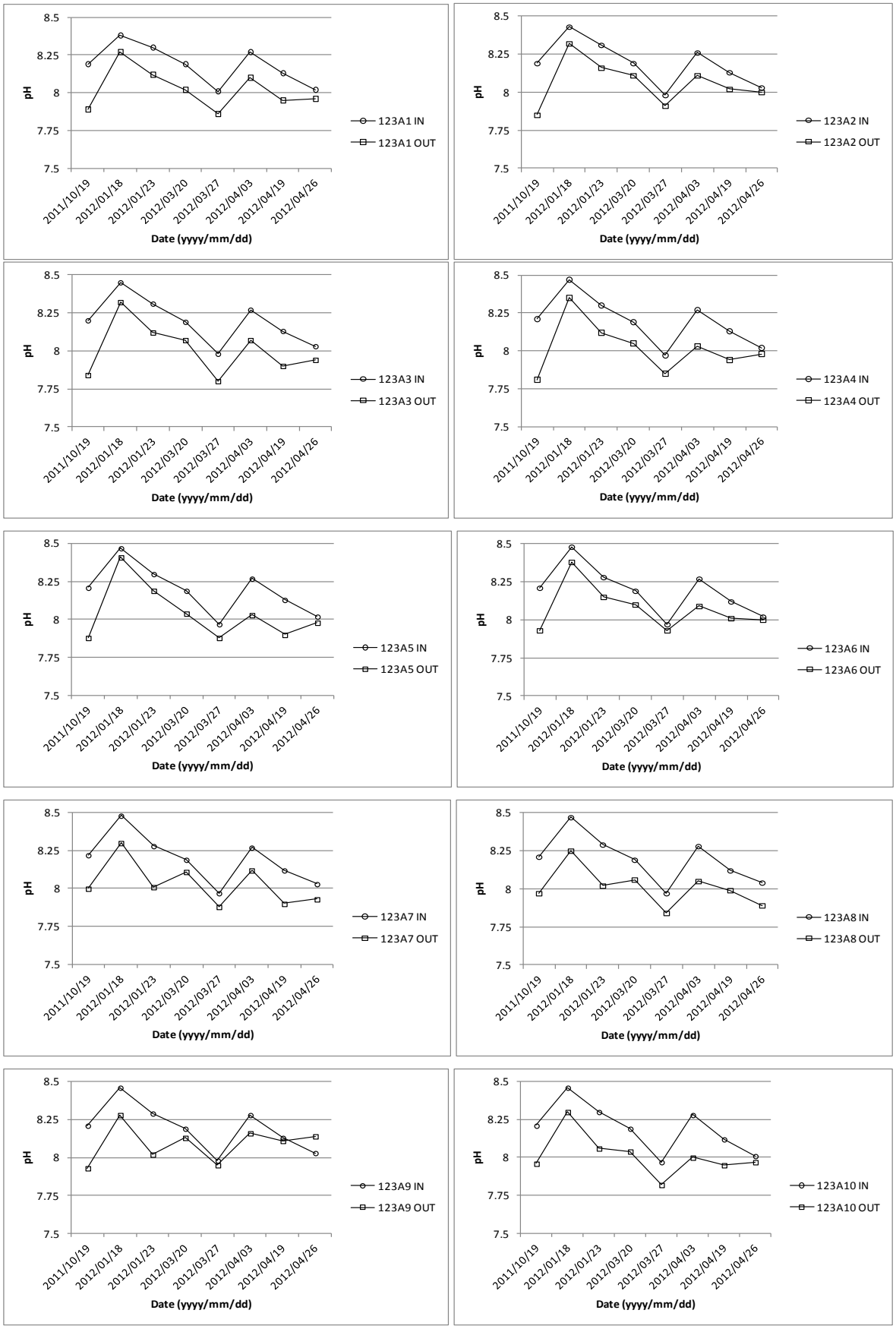


Figure C.1.6.3 *– Row 123A abalone tank pH*

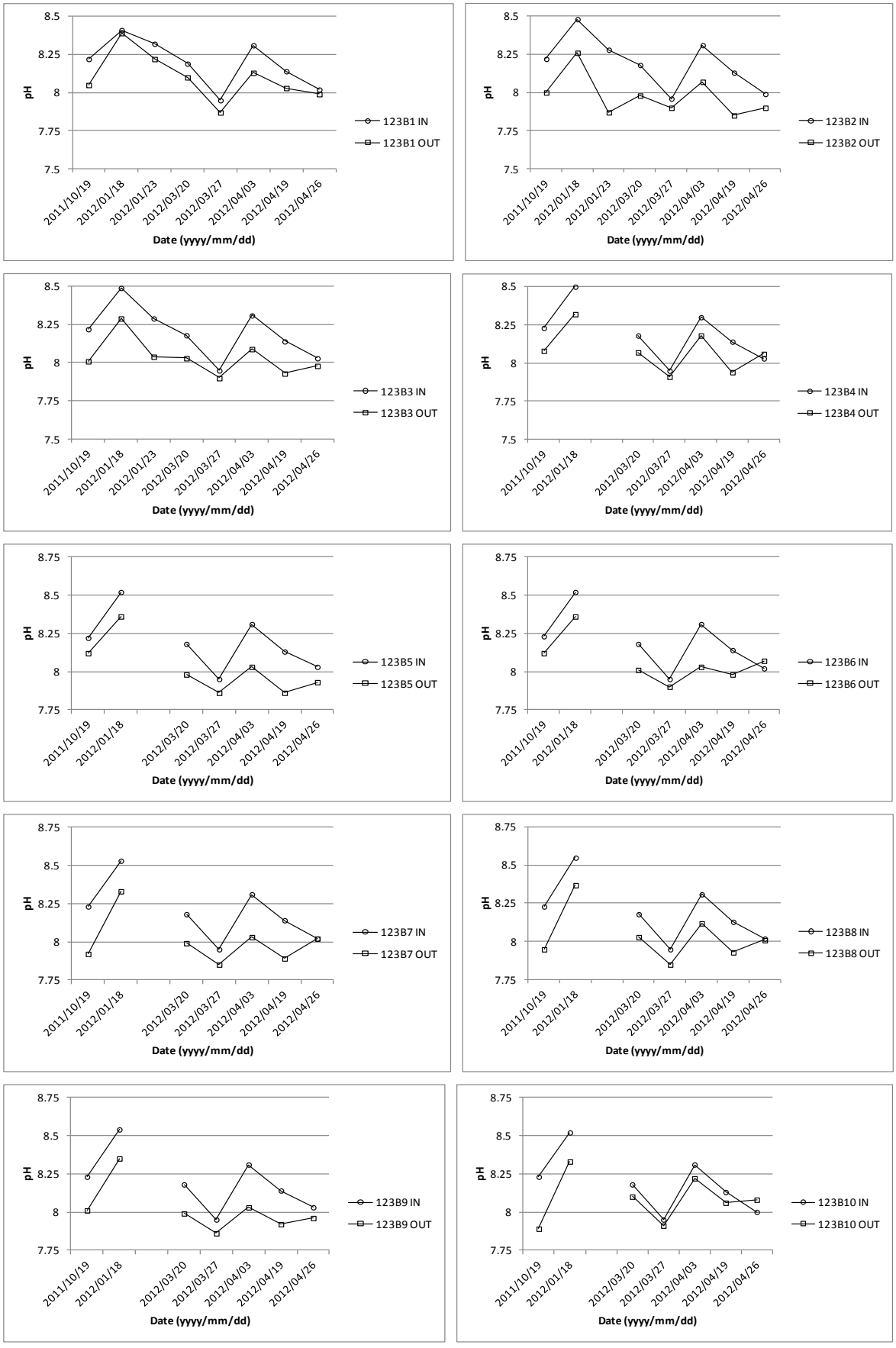


Figure C.1.6.4 *– Row 123B abalone tank pH*

C.1.7 Turbidity

Table C.1.7 *– Abalone tank turbidity*

	122A1 IN	122A1 OUT	122A2 IN	122A2 OUT	122A3 IN	122A3 OUT	122A4 IN	122A4 OUT	122A5 IN	122A5 OUT	122A6 IN	122A6 OUT	122A7 IN	122A7 OUT	122A8 IN	122A8 OUT	122A9 IN	122A9 OUT	122A10 IN	122A10 OUT
2011/10/17	0.31	0.43	0.30	0.45	0.25	0.48	0.26	0.45	0.24	0.30	0.32	0.53	0.38	0.40	0.55	0.42	0.24	0.30	0.32	0.53
2011/10/18	0.70	0.54	0.49	0.40	0.19	0.53	0.26	0.32	0.18	0.32	0.19	0.44	0.21	0.28	0.17	0.23	0.43	0.46	0.20	0.35
2011/11/01	2.63	1.48	2.49	2.02	2.03	1.67	2.03	1.12	2.10	1.79	1.80	1.18	1.88	1.55	1.48	1.61	1.98	1.73	2.18	1.53
2012/01/17	0.99	0.59	0.81	0.48	0.88	0.47	0.68	0.41	0.91	0.37	0.78	0.35	0.78	0.43	0.69	0.40	0.61	0.41	0.65	0.32
2012/01/24	0.53	0.32	1.19	0.36	0.64	0.37	0.94	0.35	0.51	0.31	0.40	0.36	0.49	0.29	0.57	0.32	0.53	0.39	0.58	0.26
2012/02/01	0.91	0.77	1.11	0.49	0.82	0.54	0.99	0.49	1.29	0.38	0.78	0.55	0.77	0.39	0.77	0.64	0.88	0.43	1.08	0.51
2012/02/07	0.42	0.34	0.68	0.30	0.75	0.34	2.30	0.36	1.07	0.39	2.12	0.36	1.70	0.44	0.62	0.37	0.29	0.31	2.04	0.32
2012/02/14	0.99	0.44	1.77	0.40	0.97	0.41	1.06	0.34	1.05	0.43	0.70	0.42	0.75	0.30	0.95	0.35	0.69	0.35	0.69	0.35
2012/02/23	0.39	0.37	0.46	0.32	0.39	0.34	0.36	0.27	0.40	0.29	0.42	0.32	0.50	0.27	0.39	0.33	0.35	0.43	0.44	0.25
2012/02/29	0.56	0.44	0.88	0.38	1.00	0.40	1.65	0.38	0.52	0.38	0.52	0.40	0.49	0.42	0.54	0.39	0.42	0.38	0.95	0.51
2012/03/07	0.87	0.40	2.18	0.61	1.64	0.40	1.88	0.42	1.87	0.44	1.23	0.41	1.03	0.39	0.86	0.31	1.53	0.46	1.15	0.41
2012/03/22	1.56	0.79	1.78	0.85	1.78	0.85	2.06	0.68	2.01	0.74	1.42	0.66	1.64	0.85	1.45	0.89	1.48	0.76	1.29	0.75
2012/03/28	0.77	0.42	1.28	0.34	0.69	0.32	2.01	0.28	1.56	0.29	0.60	0.27	1.09	0.31	1.01	0.38	0.63	0.37	0.57	0.49
2012/04/04	0.91	0.54	1.72	0.48	0.89	0.47	2.79	0.47	1.11	0.46	0.85	0.50	0.95	0.50	0.88	0.48	0.92	0.46	1.21	0.48
2012/04/18	1.17	0.58	8.75	0.57	1.50	0.60	6.23	0.55	2.87	0.58	1.39	0.61	1.92	0.74	0.92	0.54	0.71	0.47	1.03	0.49
2012/04/24	1.14	0.50	1.58	0.50	1.17	0.50	6.17	0.51	1.45	0.47	0.90	0.54	0.91	0.50	1.05	0.49	0.72	0.53	1.66	0.59

DATE	122B1 IN	122B1 OUT	122B2 IN	122B2 OUT	122B3 IN	122B3 OUT	122B4 IN	122B4 OUT	122B5 IN	122B5 OUT	122B6 IN	122B6 OUT	122B7 IN	122B7 OUT	122B8 IN	122B8 OUT	122B9 IN	122B9 OUT	122B10 IN	122B10 OUT
2011/10/17	0.21	0.34	0.27	0.35	0.25	0.40	0.37	0.39	0.48	0.29	0.23	0.38	0.34	0.40	0.35	0.38	0.28	0.44	0.32	0.43
2011/10/18	0.27	0.33	0.18	0.35	0.22	0.24	0.17	0.23	0.19	0.24	0.24	0.23	0.22	0.40	0.16	0.30	0.15	0.40	0.14	0.31
2011/11/01	2.23	1.52	1.85	1.54	2.28	1.90	2.05	1.60	1.94	1.62	2.37	1.70	1.63	1.99	2.01	1.90	2.21	1.63	2.10	1.93
2012/01/17	0.70	0.49	0.71	0.45	0.63	0.43	0.63	0.38	0.75	0.40	0.65	0.67	0.75	0.50	0.72	0.42	0.75	0.47	0.60	0.47
2012/01/24	0.41	0.39	0.57	0.31	0.44	0.46	0.49	0.36	0.33	0.28	0.39	0.38	0.65	0.35	0.40	0.34	0.59	0.35	0.34	0.27
2012/02/01	0.89	0.31	0.71	0.32	1.10	0.53	0.61	0.55	0.64	0.53	0.66	0.68	1.57	0.63	0.64	0.73	0.65	0.72	1.58	1.29
2012/02/07	0.52	0.25	0.34	0.25	0.55	0.31	0.33	0.24	0.31	0.36	0.49	0.21	0.56	0.29	0.36	0.24	0.42	0.27	0.81	0.40
2012/02/14	1.03	0.33	2.09	0.45	1.41	0.43	1.67	0.40	1.06	0.35	0.61	0.40	2.10	0.34	0.87	0.31	1.04	0.33	1.49	0.35
2012/02/23	0.56	0.41	0.52	0.35	0.45	0.39	0.48	0.38	0.40	0.32	0.39	0.39	0.40	0.33	0.45	0.35	0.40	0.32	0.40	0.39
2012/02/29	1.77	0.35	2.08	0.35	0.97	0.55	1.21	0.51	1.27	0.50	0.65	0.49	1.78	0.49	3.05	0.42	1.01	0.46	2.86	0.36
2012/03/07	0.89	0.38	1.43	0.42	0.74	0.45	0.91	0.45	0.58	0.42	0.76	0.51	0.79	0.46	0.93	0.50	0.85	0.51	0.89	0.40
2012/03/22	1.08	0.87	1.82	0.89	1.36	0.66	1.64	0.74	1.60	0.67	1.44	0.71	2.64	0.71	2.75	0.63	1.57	0.64	1.29	0.79
2012/03/28	0.67	0.37	1.43	0.38	1.17	0.36	0.86	0.37	0.91	0.34	0.72	0.39	3.72	0.38	3.40	0.40	0.93	0.38	0.78	0.55
2012/04/04	1.55	0.45	1.10	0.58	0.96	0.45	1.41	0.47	0.67	0.48	0.93	0.46	2.91	0.50	3.51	0.51	1.14	0.42	0.73	0.51
2012/04/18	0.89	0.40	3.06	0.53	0.90	0.52	0.89	0.55	0.77	0.57	0.98	0.62	1.65	0.82	6.85	0.65	1.09	0.44	0.94	0.51
2012/04/24	0.99	0.44	2.28	0.62	0.99	0.61	2.19	0.56	1.07	0.50	1.30	0.51	2.61	0.47	2.30	0.46	1.21	0.51	0.99	0.83

DATE	123A1 IN	123A1 OUT	123A2 IN	123A2 OUT	123A3 IN	123A3 OUT	123A4 IN	123A4 OUT	123A5 IN	123A5 OUT	123A6 IN	123A6 OUT	123A7 IN	123A7 OUT	123A8 IN	123A8 OUT	123A9 IN	123A9 OUT	123A10 IN	123A10 OUT
2011/10/17	0.25	0.34	0.33	0.56	0.33	0.42	0.33	0.46	0.33	0.39	0.53	0.46	0.41	0.40	0.44	0.31	0.16	0.32	0.34	0.39
2011/10/18	0.21	0.35	0.15	0.30	0.15	0.34	0.15	0.34	0.18	0.31	0.22	0.39	0.19	0.39	0.24	0.26	0.16	0.29	0.24	0.31
2011/11/01	2.18	1.73	2.19	1.65	2.38	2.34	1.25	2.29	1.82	2.25	2.01	1.80	1.43	1.89	1.67	1.47	1.65	1.48	1.82	1.19
2012/01/17	0.62	0.78	0.65	0.67	0.63	0.83	0.56	0.59	0.67	0.55	0.63	0.41	0.60	0.43	0.59	0.45	0.59	0.41	0.63	0.40
2012/01/24	0.38	0.55	0.37	0.48	0.42	0.44	0.39	0.36	0.38	0.30	0.34	0.40	0.32	0.35	0.30	0.40	0.30	0.36	0.24	0.32
2012/02/01	1.01	0.52	0.77	0.35	0.67	0.41	0.64	0.36	0.74	0.34	0.88	0.31	0.87	0.35	0.77	0.41	0.68	0.44	0.78	0.56
2012/02/07	0.66	0.51	0.88	0.35	0.99	0.37	0.97	0.33	0.66	0.29	0.57	0.37	1.08	0.33	1.18	0.36	0.62	0.38	0.89	0.39
2012/02/14	0.84	0.62	1.42	0.41	1.64	0.38	2.93	0.36	1.12	0.29	1.08	0.39	0.97	0.40	2.78	0.34	1.03	0.37	1.10	0.31
2012/02/23	0.47	0.37	0.54	0.42	0.50	0.29	0.60	0.30	0.40	0.29	0.42	0.32	0.50	0.27	0.39	0.33	0.35	0.43	0.44	0.25
2012/02/29	0.84	0.37	1.43	0.32	1.54	0.31	1.46	0.30	0.76	0.23	0.80	0.27	0.67	0.44	0.76	0.42	0.67	0.31	1.47	0.31
2012/03/07	0.97	0.54	1.79	0.48	3.03	0.49	2.80	0.47	1.14	0.40	0.90	0.40	0.88	0.46	1.28	0.49	0.67	0.38	1.09	0.37
2012/03/22	2.10	0.80	2.12	0.85	1.35	0.81	4.03	0.81	1.41	0.77	1.12	0.87	1.12	0.86	1.25	0.80	1.28	0.79	1.51	0.81
2012/03/28	0.63	0.41	0.98	0.34	0.87	0.34	1.73	0.36	0.70	0.34	1.01	0.37	0.68	0.34	0.99	0.33	1.36	0.32	0.81	0.51
2012/04/04	1.28	0.42	1.22	0.46	1.19	0.40	1.62	0.41	1.12	0.40	0.86	0.41	0.80	0.43	1.23	0.41	1.16	0.45	1.60	0.43
2012/04/18	1.23	0.48	1.18	0.48	2.69	0.47	3.11	0.50	2.09	0.46	0.92	0.47	1.61	0.43	2.27	0.45	3.46	0.49	1.00	0.47
2012/04/24	0.98	0.52	1.45	0.52	1.14	0.46	1.29	0.51	1.25	0.57	1.19	0.50	1.62	0.38	2.83	0.67	1.62	0.50	1.61	0.75

DATE	123B1 IN	123B1 OUT	123B2 IN	123B2 OUT	123B3 IN	123B3 OUT	123B4 IN	123B4 OUT	123B5 IN	123B5 OUT	123B6 IN	123B6 OUT	123B7 IN	123B7 OUT	123B8 IN	123B8 OUT	123B9 IN	123B9 OUT	123B10 IN	123B10 OUT
2011/10/17	0.29	0.54	0.26	0.47	0.28	0.42	0.22	0.44	0.19	0.40	0.31	0.32	0.25	0.34	0.24	0.44	0.31	0.53	0.29	0.44
2011/10/18					0.64	0.82	0.24	0.36	0.18	0.46	0.15	0.26	0.23	0.24	0.23	0.25	0.21	0.33	0.16	0.31
2011/11/01																				
2012/01/17	0.70	0.57	0.79	0.45	0.75	0.46	0.73	0.39	0.63	0.45	0.68	0.41	0.62	0.43	0.61	0.66	0.54	0.48	0.55	0.50
2012/01/24	0.44	0.31	0.47	0.51	0.34	0.38	0.28	0.33	0.33	0.28	0.41	0.45	0.47	0.37	0.38	0.41	0.46	0.34	0.43	0.42
2012/02/01	0.94	0.43	1.08	0.41	0.84	0.48	0.71	0.46	0.77	0.39	1.69	0.45	0.89	0.43	0.65	0.43	0.97	0.38	0.97	0.45
2012/02/07	0.56	0.41	0.68	0.60	0.54	0.58	0.59	0.49	0.62	0.56	1.19	0.63	0.77	1.02	1.03	0.94	0.71	0.94	0.79	0.49
2012/02/14	1.77	0.47	0.83	0.40	0.78	0.35	0.59	0.40	0.65	0.32	0.64	0.36	0.58	0.49	0.65	0.49	0.64	0.37	0.63	0.37
2012/02/23	0.47	0.35	0.37	0.37	0.42	0.40	0.35	0.38	0.38	0.39	0.34	0.36	0.43	0.41	0.35	0.41	0.35	0.38	0.37	0.37
2012/02/29	0.84	0.32	0.88	0.43	2.18	0.46	0.68	0.41	0.74	0.40	0.98	0.35	1.04	0.37	0.72	0.38	0.78	0.47	1.96	0.37
2012/03/07	2.51	0.32	0.96	0.34	2.84	0.50	0.92	0.46	1.02	0.40	0.81	0.39	1.17	0.42	0.61	0.46	1.29	0.51	1.77	0.51
2012/03/22	2.05	0.78	1.43	0.76	3.50	0.78	1.43	0.85	3.88	0.90	1.24	0.79	1.25	0.78	0.89	0.74	1.57	0.74	1.63	0.85
2012/03/28	1.06	0.45	0.73	0.41	2.98	0.36	0.73	0.38	1.55	0.39	0.93	0.34	0.90	0.44	0.99	0.46	2.96	0.31	1.05	0.36
2012/04/04	0.92	0.39	0.71	0.39	1.07	0.39	0.62	0.43	1.29	0.39	0.85	0.41	1.02	0.39	1.04	0.40	0.74	0.37	1.04	0.41
2012/04/18	1.59	1.11	1.23	0.61	0.94	0.58	1.63	0.59	1.93	0.66	2.90	0.44	1.81	0.47	1.58	0.50	1.45	1.10	1.16	0.60
2012/04/24	1.31	0.65	1.24	0.44	2.81	0.56	1.27	0.58	1.23	0.51	1.20	0.49	1.51	0.58	1.99	0.59	1.84	0.54	1.38	0.54

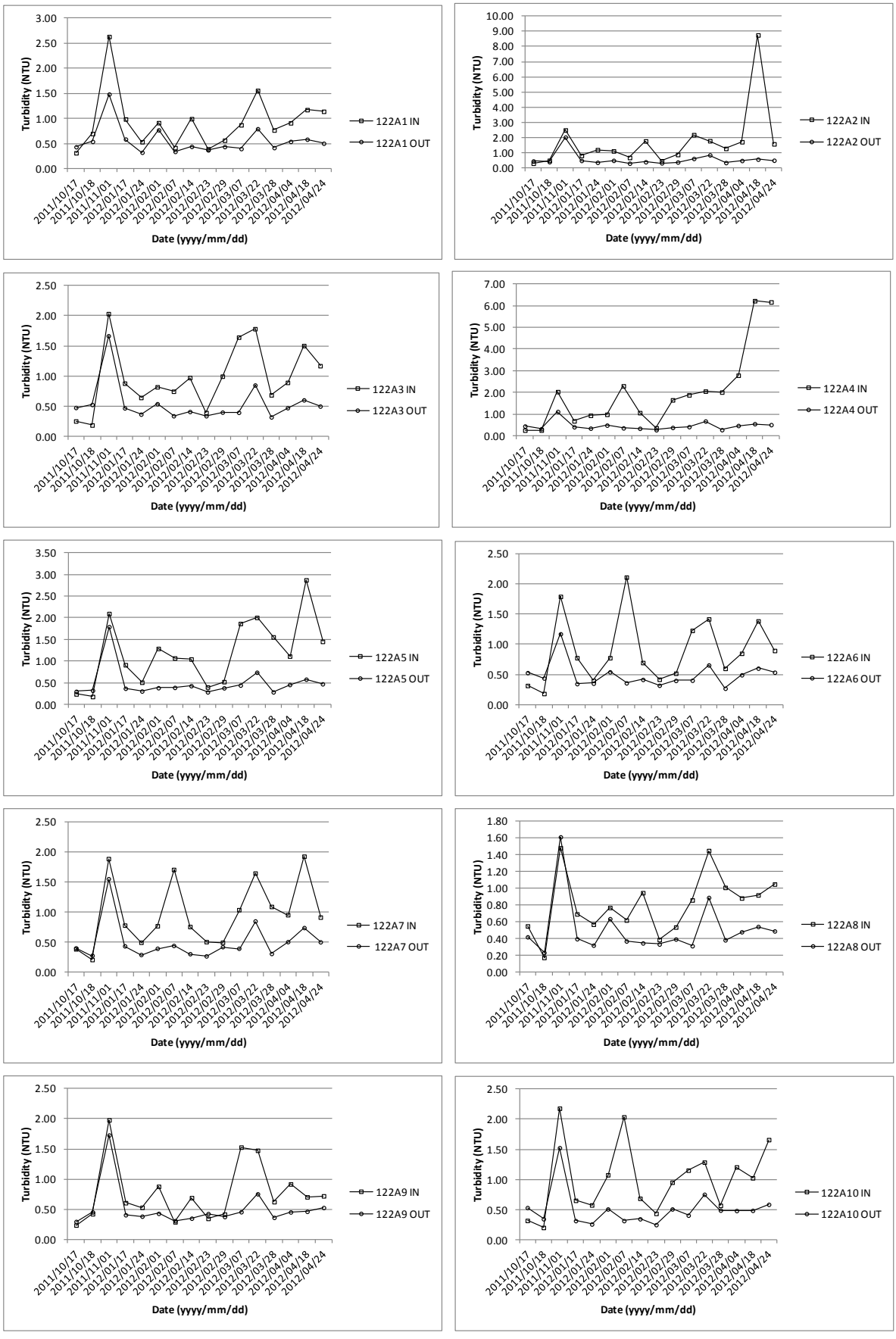


Figure C.1.7.1 *– Row 122A abalone tank turbidity*

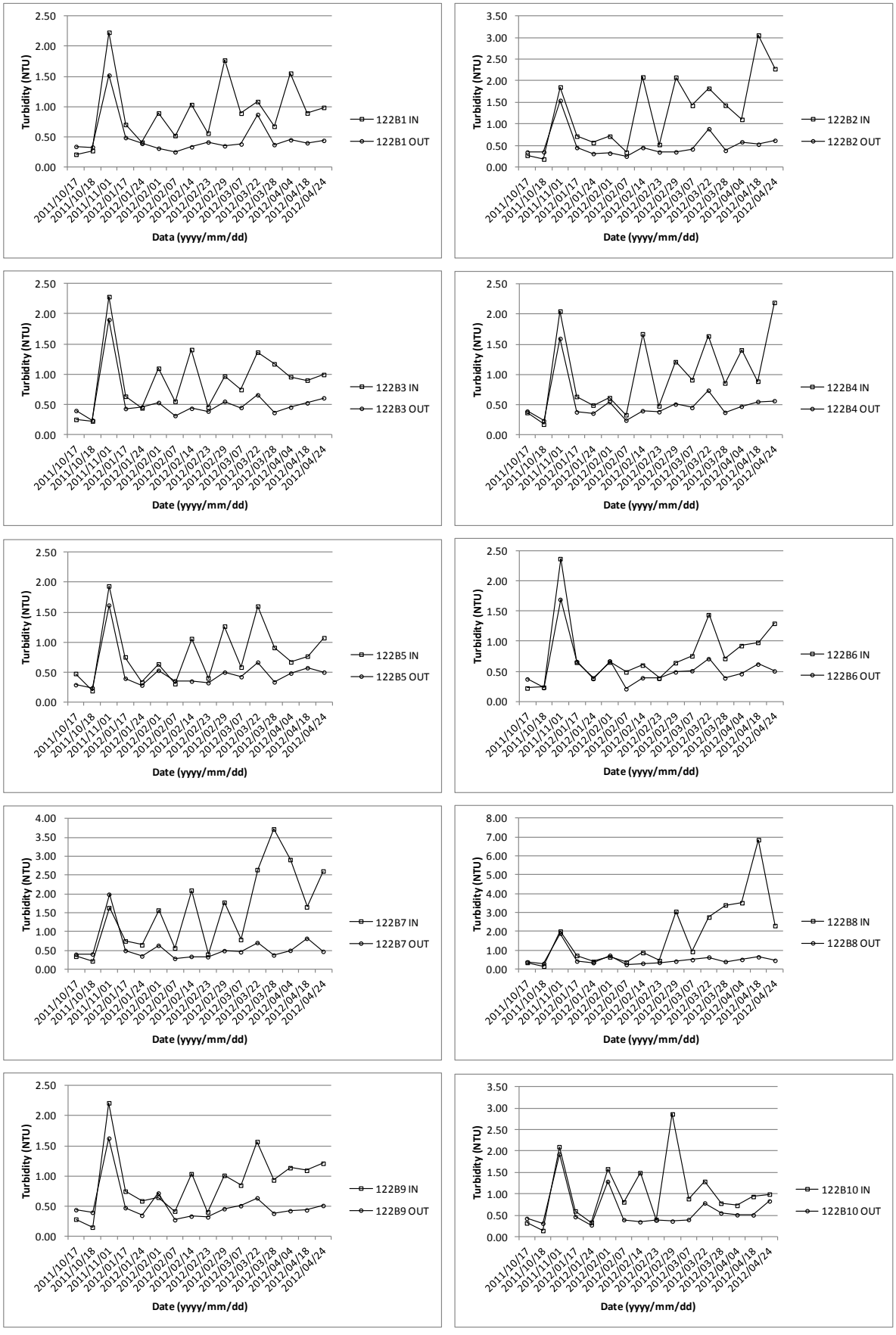


Figure C.1.7.2 *– Row 122B abalone tank turbidity*

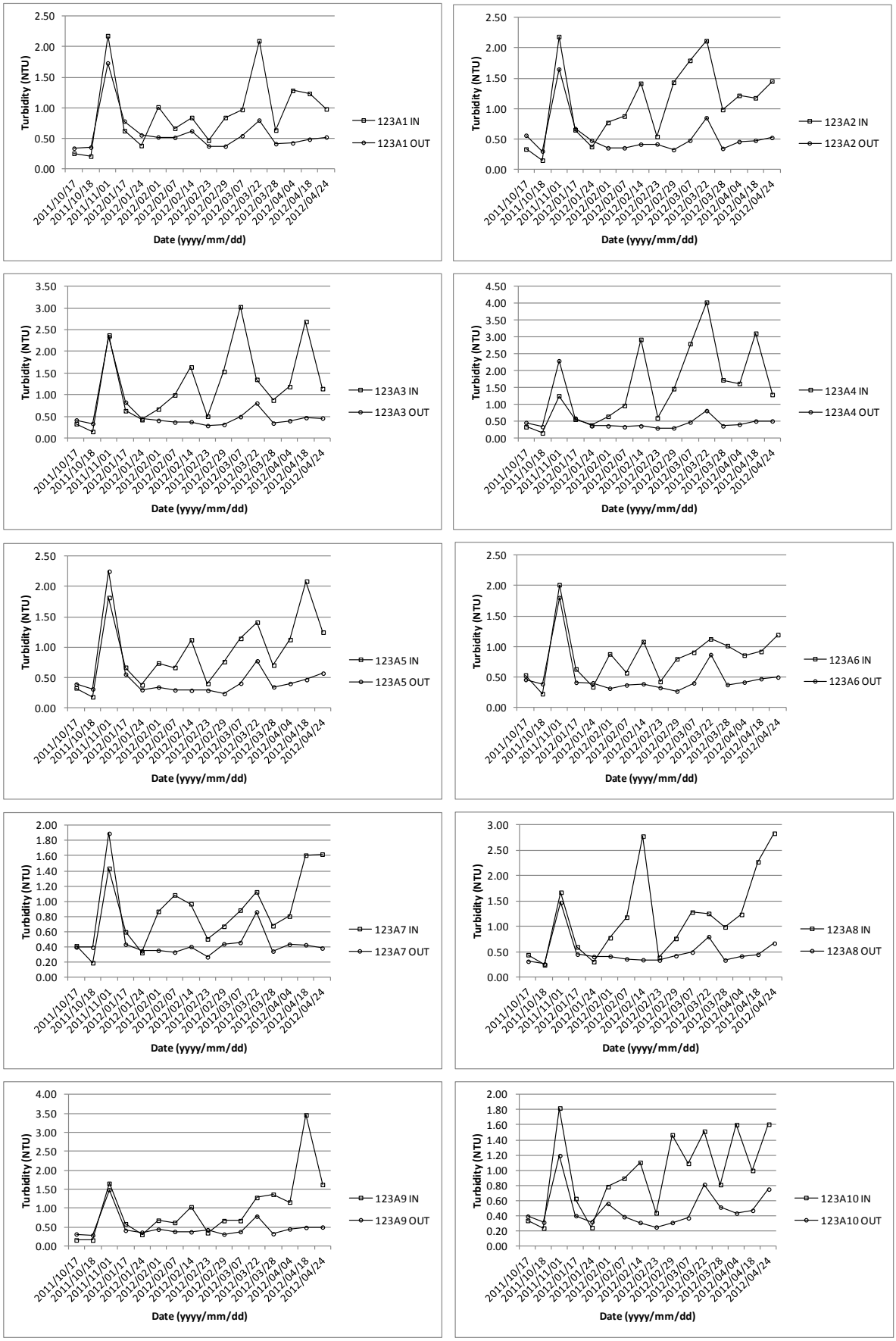


Figure C.1.7.3 *– Row 123A abalone tank turbidity*

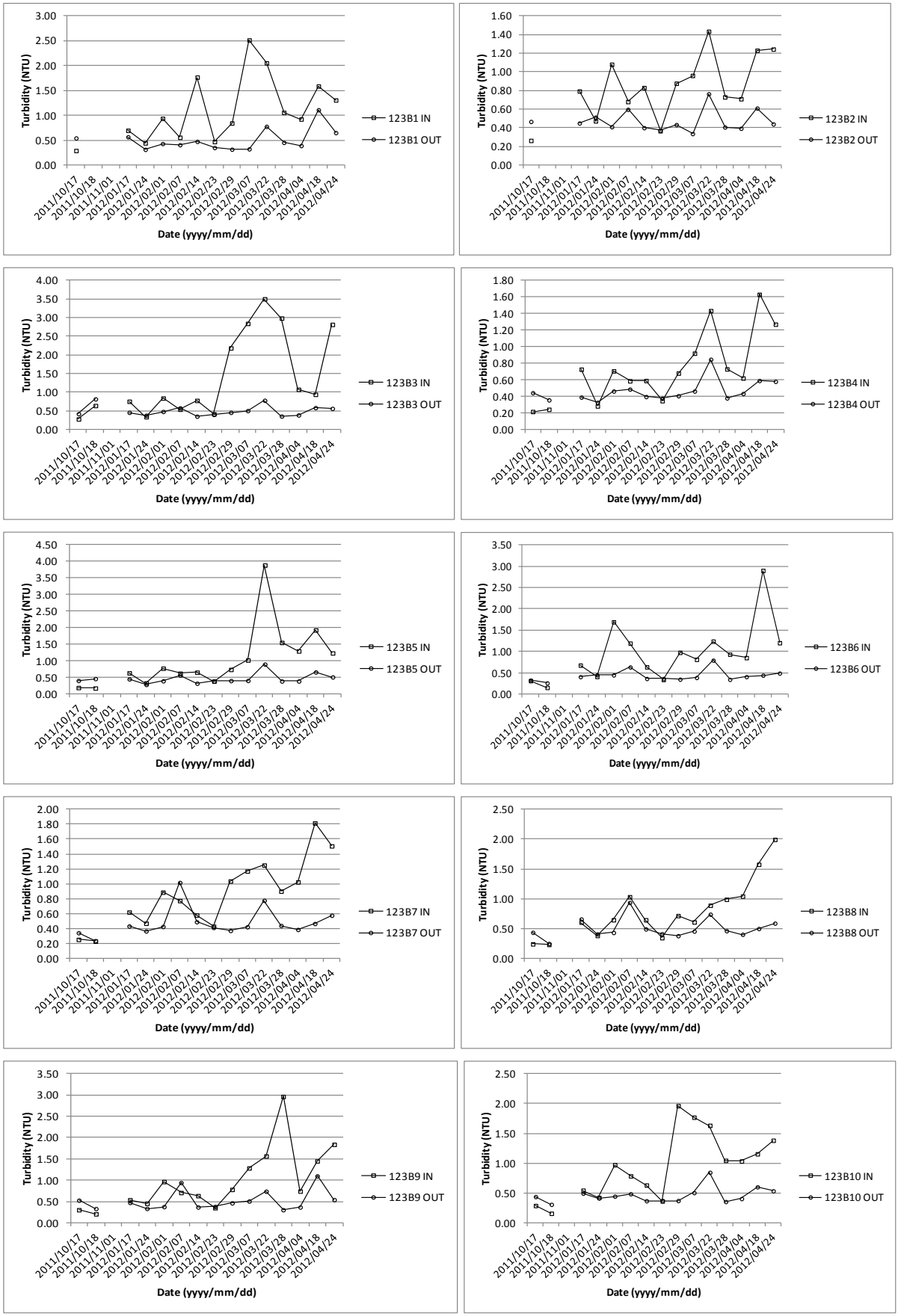


Figure C.1.7.4 *– Row 123B abalone tank turbidity*

C.2 WATER CHARACTERISATION – COMBINED STREAMS

The results for the water characterisation parameters measured for the influent, effluent, effluent 200µm, UF feed, UF permeate, RO feed, RO permeate and RO concentrate streams from March 2012 to July 2012 are summarised in this section Appendix C.

Table C.2.1 *– Influent water characterisation parameters as measured*

Site	Timestamp	Conductivity (uS/cm)	Salinity (ppt)	Specific Conductance (uS/cm)	TDS (g/L)	Temperature (C)	Barometric Pressure (kPa)	Dissolved Oxygen (mg/l)	pH (mg/l)
INFLUENT	2012/03/20 12:22	46985	35.20	53250	34.61	18.8	101.11	8.13	8.18
INFLUENT	2012/03/21 07:56	47006	35.39	53511	34.78	18.6	101.22	8.39	8.04
INFLUENT	2012/03/21 09:16	46922	35.33	53427	34.73	18.6	101.27	8.53	7.88
INFLUENT	2012/03/22 08:04	46314	35.28	53359	34.68	18.1	101.47	8.39	7.97
INFLUENT	2012/03/22 10:03	46803	35.29	53367	34.69	18.6	101.53	8.17	8.09
INFLUENT	2012/03/23 08:02	45193	35.24	53316	34.66	17	101.58	8.67	7.94
INFLUENT	2012/03/23 10:05	43857	35.17	53259	34.62	15.8	101.65	8.87	7.95
INFLUENT	2012/03/26 13:36	40639	35	53168	34.56	12.7	100.9	9.36	7.88
INFLUENT	2012/03/26 16:00	41827	34.99	53087	34.51	13.9	100.89	7.91	7.89
INFLUENT	2012/03/27 08:04	40353	35.02	53223	34.59	12.3	101.27	9.27	7.86
INFLUENT	2012/03/27 10:06	40453	34.91	53050	34.48	12.6	101.3	7.66	7.02
INFLUENT	2012/03/28 10:05	40560	35.05	53250	34.61	12.5	100.88	8.14	7.95
INFLUENT	2012/03/29 08:10	41920	35.02	53132	34.5345	14	100.76	8.53	7.95
INFLUENT	2012/03/29 10:06	41947	35	53097	34.515	14	100.72	7.75	8
INFLUENT	2012/03/30 08:13	45371	35.29	53385	34.70	17.1	101.07	8.4	8.04
INFLUENT	2012/03/30 10:22	45127	35.3	53400	34.71	16.9	101.25	6.76	8.22
INFLUENT	2012/04/02 13:51	44267	35.13	53197	34.58	16.2	101.86	8.26	8.18
INFLUENT	2012/04/03 08:23	43534	35.13	53217	34.593	15.5	101.63	8.79	8.02
INFLUENT	2012/04/03 09:36	43527	35.1	53172	34.5605	15.5	101.64	7.23	8.09
INFLUENT	2012/04/17 10:48	43477	35.1	53169	34.5605	15.5	102.04	8.45	8.1
INFLUENT	2012/04/17 15:58	43942	35.1	53161	34.554	15.9	101.99	8.43	8.12
INFLUENT	2012/04/18 08:02	43347	35.12	53202	34.58	15.3	102.24	8.56	8.04
INFLUENT	2012/04/18 12:01	43448	34.97	52993	34.44	15.6	102.23	8.65	8.11
INFLUENT	2012/04/19 08:13	42870	35.08	53166	34.5605	14.9	101.79	8.56	7.94
INFLUENT	2012/04/19 10:18	43075	35.08	53166	34.5605	15.1	101.82	8.62	8.1
INFLUENT	2012/04/20 08:28	42115	35.06	53169	34.56	14.1	101.51	8.65	7.94
INFLUENT	2012/04/20 10:40	42015	34.99	53076	34.50	14.1	101.5	8.73	8.04
INFLUENT	2012/04/23 11:56	41288	35.02	53157	34.55	13.3	102.54	8.98	8.03
INFLUENT	2012/04/23 14:41	41390	34.97	53079	34.50	13.5	102.39	9.25	8.05
INFLUENT	2012/04/24 08:15	40192	34.94	53119	34.528	12.3	102.43	9.27	7.98
INFLUENT	2012/04/24 12:25	40345	34.92	53078	34.502	12.4	102.26	9.83	8.04
INFLUENT	2012/04/25 08:01	38958	34.92	53193	34.57	11	101.59	9.72	7.91
INFLUENT	2012/04/25 14:08	38932	34.87	53120	34.53	11	101.34	9.65	7.98
INFLUENT	2012/04/26 08:46	38992	34.89	53138	34.541	11.1	101.14	9.54	7.96
INFLUENT	2012/04/26 13:45	39171	34.79	52981	34.437	11.4	100.99	8.9	8.02
INFLUENT	2012/05/14 11:53	45016	35.39	53533	34.7945	16.7	102.09	8.3	8.15
INFLUENT	2012/05/14 15:34	45327	35.38	53507	34.7815	17	102.05	8.67	8.25
INFLUENT	2012/05/15 08:33	44146	35.37	53525	34.7945	15.8	102.3	8.62	8.14
INFLUENT	2012/05/15 15:34	44611	35.25	53344	34.671	16.4	102.07	8.3	8.23
INFLUENT	2012/05/16 08:42	44132	35.32	53454	34.7425	15.9	101.89	8.5	8.14
INFLUENT	2012/05/16 16:06	44623	35.33	53461	34.749	16.3	101.57	8.41	8.29
INFLUENT	2012/05/17 08:58	44041	35.31	53450	34.7425	15.8	101.14	8.33	8.03
INFLUENT	2012/05/17 13:23	44317	35.28	53395	34.71	16.1	100.78	8.25	8.19
INFLUENT	2012/05/22 16:11	44502	35.4	53553	34.8075	16.2	100.91	8.16	8.25
INFLUENT	2012/05/23 10:13	44460	35.39	53540	34.801	16.1	100.89	7.94	8.24
INFLUENT	2012/05/23 12:13	44502	35.38	53529	34.7945	16.2	100.87	8.09	8.26
INFLUENT	2012/05/24 09:01	44110	35.4	53574	34.8205	15.8	101.38	8.31	8.07
INFLUENT	2012/05/24 12:30	44540	35.42	53587	34.8335	16.2	101.36	8.54	8.28
INFLUENT	2012/05/24 15:53	44616	35.33	53461	34.749	16.3	101.27	8.79	8.2
INFLUENT	2012/05/25 09:12	44247	35.39	53546	34.8075	15.9	101.21	7.69	8.15
INFLUENT	2012/05/25 12:38	44466	35.36	53498	34.775	16.2	101.17	7.86	8.26
INFLUENT	2012/05/28 12:08	45022	35.49	53667	34.8855	16.6	101.52	7.78	8.26
INFLUENT	2012/05/28 14:01	45226	35.55	53751	34.9375	16.7	101.44	7.82	8.28
INFLUENT	2012/05/29 08:48	44883	35.5	53682	34.892	16.4	101.59	7.58	8.24
INFLUENT	2012/05/29 15:20	44870	35.44	53605	34.8465	16.5	101.95	8	8.23
INFLUENT	2012/05/30 09:05	44900	35.52	53711	34.9115	16.4	102.69	7.7	8.24
INFLUENT	2012/05/30 15:35	45333	35.53	53715	34.918	16.8	102.7	7.97	8.32
INFLUENT	2012/05/31 09:00	44728	35.47	53654	34.8725	16.3	102.69	7.88	8.29
INFLUENT	2012/05/31 14:23	45176	35.52	53710	34.9115	16.7	102.42	8	8.33
INFLUENT	2012/06/01 08:58	44769	35.51	53698	34.905	16.3	102.63	7.87	8.31
INFLUENT	2012/06/01 11:20	45014	35.48	53657	34.879	16.6	102.71	7.9	8.37
INFLUENT	2012/06/11 14:04	44293	35.47	53655	34.879	15.9	102.25	7.89	8.23
INFLUENT	2012/06/11 15:27	44268	35.44	53622	34.853	15.9	102.16	8.02	8.35
INFLUENT	2012/06/12 08:39	43975	35.48	53684	34.892	15.5	102.12	7.88	8.33
INFLUENT	2012/06/12 15:50	44075	35.47	53662	34.879	15.6	102.35	7.99	8.34
INFLUENT	2012/06/13 08:53	43768	35.47	53676	34.892	15.3	102.53	7.95	8.25
INFLUENT	2012/06/13 15:01	43894	35.45	53646	34.8725	15.5	102.19	8.06	8.3
INFLUENT	2012/06/14 09:28	42821	35.39	53608	34.8465	14.5	101.64	8.13	8.19
INFLUENT	2012/06/14 14:53	44131	35.47	53671	34.8855	15.7	101.31	8.2	8.37
INFLUENT	2012/06/15 09:02	43587	35.47	53691	34.8985	15.1	101.33	7.91	8.19
INFLUENT	2012/06/15 10:42	43746	35.42	53615	34.8465	15.4	101.43	8.06	8.31
INFLUENT	2012/06/18 13:16	43808	35.44	53641	34.866	15.4	102.69	8.07	8.29
INFLUENT	2012/06/18 16:11	43636	35.37	53540	34.801	15.3	102.7	8.12	8.23
INFLUENT	2012/06/19 08:49	42793	35.37	53574	34.8205	14.5	102.6	8.15	8.15
INFLUENT	2012/06/19 12:40	43211	35.41	53614	34.8465	14.8	102.58	8.56	8.36
INFLUENT	2012/06/20 09:42	43381	35.41	53614	34.8465	15	102.7	8.09	8.3
INFLUENT	2012/06/20 15:07	43305	35.36	53544	34.801	15	102.45	8.24	8.32
INFLUENT	2012/06/21 08:52	42423	35.35	53565	34.814	14.1	101.93	8.29	8.18
INFLUENT	2012/06/21 14:13	42568	35.33	53526	34.7945	14.3	101.53	8.54	8.24
INFLUENT	2012/06/22 08:24	42352	35.33	53540	34.801	14.1	101.35	8.36	8.17
INFLUENT	2012/06/22 10:12	42642	35.35	53559	34.814	14.3	101.37	8.52	8.24
INFLUENT	2012/06/25 12:34	43199	35.41	53613	34.8465	14.8	101.56	8.19	8.32
INFLUENT	2012/06/25 14:37	43518	35.4	53585	34.827	15.2	101.47	8.35	8.34
INFLUENT	2012/06/26 09:08	43294	35.47	53695	34.905	14.9	100.9	8.33	8.3
INFLUENT	2012/06/26 14:09	43221	35.37	53554	34.8075	14.9	100.96	8.13	8.31
INFLUENT	2012/06/27 09:04	43062	35.41	53624	34.853	14.7	102.3	8.13	8.24
INFLUENT	2012/06/27 14:29	43409	35.41	53604	34.84	15	102.28	8.18	8.28
INFLUENT	2012/06/28 09:00	43048	35.43	53653	34.8725	14.7	101.73	8.19	8.24
INFLUENT	2012/06/28 15:00	43502	35.45	53657	34.879	15.1	101.37	8.11	8.37
INFLUENT	2012/06/29 08:57	43005	35.43	53647	34.8725	14.6	101.68	8.05	7.96
INFLUENT	2012/06/29 10:49	43304	35.44	53653	34.8725	14.9	101.6	8.15	7.99
INFLUENT	2012/07/02 12:43	43075	35.35	53542	34.801	14.8	101.84	8.23	8.09
INFLUENT	2012/07/02 14:40	43086	35.41	53617	34.853	14.7	101.77	8.77	8.14
INFLUENT	2012/07/03 10:23	42760	35.32	53501	34.775	14.5	101.35	8.54	8.08
INFLUENT	2012/07/03 11:58	43044	35.38	53573	34.8205	14.7	101.25	8.07	8.1
INFLUENT	2012/07/04 09:17	42584	35.41	53644	34.866	14.2	101.86	8.2	7.9
INFLUENT	2012/07/04 11:30	42737	35.42	53644	34.866	14.4	102.01	8.25	7.86
INFLUENT	2012/07/05 09:28	42394	35.45	53703	34.905	14	101.46	8	8.02
INFLUENT	2012/07/05 11:19	42444	35.22	53386	34.7035	14.3	101.41	8.44	8.07
INFLUENT	2012/07/06 09:40	42534	35.34	53545	34.801	14.2	100.98	7.97	7.98
INFLUENT	2012/07/06 12:16	42890	35.36	53560	34.814	14.6	100.88	8.17	7.07
INFLUENT	2012/07/09 12:17	42864	35.37	53572	34.8205	14.5	102.08	8.02	8
INFLUENT	2012/07/09 13:41	43099	35.42	53629	34.8595	14.7	101.95	8.24	8.09

Table C.2.2 *– Effluent water characterisation parameters as measured*

Site	Timestamp	Conductivity (uS/cm)	Salinity (ppt)	Specific Conductance (uS/cm)	TDS (g/L)	Temperature (C)	Barometric Pressure (kPa)	Dissolved Oxygen (mg/l)	pH (mg/l)
EFFLUENT	2012/03/20 15:22	47651	35.39	53498	34.78	19.3	101	7.48	8.03
EFFLUENT	2012/03/21 07:57	46758	35.36	53464	34.75	18.4	101.23	7.75	7.87
EFFLUENT	2012/03/21 09:17	46725	35.31	53396	34.71	18.5	101.3	7.72	7.84
EFFLUENT	2012/03/22 08:05	46500	35.29	53370	34.69	18.3	101.48	7.59	7.79
EFFLUENT	2012/03/22 10:04	46616	35.27	53347	34.68	18.4	101.53	7.38	7.84
EFFLUENT	2012/03/23 08:04	45288	35.22	53291	34.64	17.1	101.59	7.89	7.81
EFFLUENT	2012/03/23 10:06	44742	35.16	53228	34.60	16.7	101.65	7.81	7.8
EFFLUENT	2012/03/26 13:37	40632	35	53170	34.56	12.7	100.91	8.84	7.8
EFFLUENT	2012/03/26 16:01	41220	34.99	53115	34.53	13.3	100.89	8.09	7.88
EFFLUENT	2012/03/27 08:01	40615	35.00	53174	34.56	12.6	101.27	9.72	7.8
EFFLUENT	2012/03/27 10:07	39655	34.19	52074	33.85	12.5	101.32	7.75	7.84
EFFLUENT	2012/03/28 10:06	40530	34.99	53171	34.56	12.6	100.88	7.97	7.84
EFFLUENT	2012/03/29 08:11	41214	35.01	53144	34.541	13.2	100.78	8.55	7.89
EFFLUENT	2012/03/29 10:07	41483	35.01	53134	34.5345	13.5	100.73	7.78	7.85
EFFLUENT	2012/03/30 08:14	44828	35.26	53353	34.68	16.6	101.08	7.92	7.92
EFFLUENT	2012/03/30 10:23	45143	35.28	53375	34.70	16.9	101.26	6.77	8.04
EFFLUENT	2012/04/02 13:52	44089	35.15	53220	34.59	16	101.86	8.01	8.04
EFFLUENT	2012/04/03 08:25	43969	35.16	53244	34.606	15.9	101.63	8.07	7.91
EFFLUENT	2012/04/03 09:37	43635	35.14	53218	34.593	15.6	101.64	6.85	7.97
EFFLUENT	2012/04/17 10:49	43540	35.16	53251	34.6125	15.5	102.04	7.76	7.89
EFFLUENT	2012/04/17 16:00	43899	35.11	53177	34.567	15.9	101.98	7.73	7.97
EFFLUENT	2012/04/18 08:03	43303	35.14	53234	34.60	15.2	102.24	7.9	7.91
EFFLUENT	2012/04/18 12:02	43516	35.14	53228	34.60	15.4	102.22	7.95	7.97
EFFLUENT	2012/04/19 08:15	42748	35.11	53213	34.5865	14.7	101.79	7.86	7.87
EFFLUENT	2012/04/19 10:19	43031	35.07	53146	34.5475	15	101.82	7.98	7.97
EFFLUENT	2012/04/20 08:30	42051	35.07	53188	34.57	14	101.51	8.13	7.9
EFFLUENT	2012/04/20 10:43	42073	35.01	53100	34.52	14.1	101.5	8.24	7.91
EFFLUENT	2012/04/23 11:57	41034	35.02	53179	34.57	13	102.54	8.5	7.9
EFFLUENT	2012/04/23 14:43	41419	35.05	53199	34.58	13.4	102.39	8.47	7.99
EFFLUENT	2012/04/24 07:57	40451	34.99	53165	34.5605	12.5	102.4	8.83	7.78
EFFLUENT	2012/04/24 12:26	40314	34.93	53089	34.5085	12.4	102.25	8.94	7.96
EFFLUENT	2012/04/25 08:02	38904	34.93	53204	34.58	10.9	101.58	9.19	7.92
EFFLUENT	2012/04/25 14:09	39018	34.9	53158	34.55	11.1	101.34	9.11	7.97
EFFLUENT	2012/04/26 08:48	38863	34.92	53195	34.58	10.9	101.14	9.13	7.88
EFFLUENT	2012/04/26 13:49	39641	34.79	52944	34.411	11.8	101	8.56	7.99
EFFLUENT	2012/05/14 11:55	44966	35.43	53585	34.8335	16.6	102.09	7.53	7.92
EFFLUENT	2012/05/14 15:35	45161	35.34	53466	34.7555	16.9	102.06	7.52	7.96
EFFLUENT	2012/05/15 08:35	43947	35.38	53550	34.8075	15.6	102.3	7.67	7.95
EFFLUENT	2012/05/15 15:36	44427	35.33	53470	34.7555	16.1	102.07	7.52	7.99
EFFLUENT	2012/05/16 08:43	44088	35.35	53496	34.775	15.8	101.89	7.7	7.91
EFFLUENT	2012/05/16 16:07	44545	35.32	53441	34.736	16.3	101.57	7.51	8.06
EFFLUENT	2012/05/17 09:00	43917	35.32	53470	34.7555	15.6	101.14	7.62	7.81
EFFLUENT	2012/05/17 13:26	44141	35.26	53374	34.6905	15.9	100.79	7.47	8
EFFLUENT	2012/05/22 16:12	44556	35.4	53553	34.8075	16.2	100.91	7.55	8.08
EFFLUENT	2012/05/23 10:16	44092	35.38	53537	34.801	15.8	100.89	7.27	7.82
EFFLUENT	2012/05/23 12:14	44281	35.39	53546	34.8075	15.9	100.88	7.4	7.95
EFFLUENT	2012/05/24 09:03	43975	35.42	53605	34.84	15.6	101.38	7.58	7.87
EFFLUENT	2012/05/24 12:32	44357	35.42	53595	34.8335	16	101.36	7.79	8.03
EFFLUENT	2012/05/24 15:54	44725	35.42	53574	34.8205	16.4	101.26	7.66	7.94
EFFLUENT	2012/05/25 09:13	44208	35.42	53595	34.8335	15.8	101.22	6.88	7.88
EFFLUENT	2012/05/25 12:39	44392	35.37	53520	34.788	16.1	101.18	7	8.01
EFFLUENT	2012/05/28 12:09	44787	35.49	53677	34.892	16.3	101.51	7.04	8.13
EFFLUENT	2012/05/28 14:02	44965	35.48	53660	34.879	16.5	101.44	7.13	8.11
EFFLUENT	2012/05/29 08:50	44683	35.52	53713	34.9115	16.2	101.59	6.97	8
EFFLUENT	2012/05/29 15:22	44817	35.49	53672	34.8855	16.4	101.94	6.99	8.02
EFFLUENT	2012/05/30 09:07	44634	35.53	53735	34.9245	16.1	102.7	7.05	7.94
EFFLUENT	2012/05/30 15:41	45189	35.38	53512	34.7815	16.9	102.71	6.97	8.12
EFFLUENT	2012/05/31 09:01	44669	35.52	53724	34.918	16.2	102.7	7.01	7.98
EFFLUENT	2012/05/31 14:25	45174	35.52	53702	34.905	16.7	102.41	6.84	8.07
EFFLUENT	2012/06/01 09:00	44646	35.51	53705	34.9115	16.2	102.63	6.98	7.94
EFFLUENT	2012/06/01 11:25	44881	35.51	53707	34.9115	16.4	102.7	7	8.05
EFFLUENT	2012/06/11 14:05	44147	35.49	53687	34.8985	15.7	102.25	7.21	8.05
EFFLUENT	2012/06/11 15:29	44094	35.48	53687	34.8985	15.6	102.15	7.1	8.06
EFFLUENT	2012/06/12 08:40	43839	35.49	53697	34.905	15.4	102.12	7.2	8.06
EFFLUENT	2012/06/12 15:53	43788	35.31	53453	34.7425	15.5	102.34	7.24	8.08
EFFLUENT	2012/06/13 08:55	43600	35.48	53703	34.905	15.2	102.52	7.2	7.97
EFFLUENT	2012/06/13 15:02	43867	35.51	53730	34.9245	15.4	102.19	7.19	8.02
EFFLUENT	2012/06/14 09:29	43029	35.45	53685	34.892	14.6	101.63	7.32	7.99
EFFLUENT	2012/06/14 14:55	43713	35.45	53648	34.8725	15.3	101.31	7.17	8.13
EFFLUENT	2012/06/15 09:04	43453	35.48	53704	34.905	15	101.34	7.12	7.96
EFFLUENT	2012/06/15 10:45	43548	35.46	53677	34.892	15.1	101.43	7.21	8.02
EFFLUENT	2012/06/18 13:18	43699	35.46	53672	34.8855	15.3	102.7	7.13	7.94
EFFLUENT	2012/06/18 16:13	43662	35.44	53638	34.866	15.3	102.7	7.22	8.02
EFFLUENT	2012/06/19 08:55	42548	35.36	53567	34.8205	14.2	102.62	7.36	8.01
EFFLUENT	2012/06/19 12:42	43149	35.41	53612	34.8465	14.8	102.58	7.52	8.13
EFFLUENT	2012/06/20 09:43	43209	35.39	53590	34.8335	14.9	102.7	7.34	8.05
EFFLUENT	2012/06/20 15:08	43341	35.42	53623	34.853	15	102.45	7.49	8.05
EFFLUENT	2012/06/21 08:53	42277	35.33	53549	34.8075	14	101.92	7.54	7.99
EFFLUENT	2012/06/21 14:14	42664	35.35	53555	34.814	14.4	101.53	7.66	8.03
EFFLUENT	2012/06/22 08:26	42260	35.33	53543	34.801	14	101.36	7.42	7.96
EFFLUENT	2012/06/22 10:14	42425	35.34	53553	34.8075	14.1	101.37	7.64	8.03
EFFLUENT	2012/06/25 12:37	42605	35.38	53597	34.84	14.3	101.55	7.26	7.87
EFFLUENT	2012/06/25 14:39	43130	35.44	53656	34.879	14.7	101.48	7.27	8.05
EFFLUENT	2012/06/26 09:10	43127	35.48	53714	34.9115	14.7	100.88	7.18	7.98
EFFLUENT	2012/06/26 14:11	42797	35.03	53103	34.515	14.8	101	7.48	8.06
EFFLUENT	2012/06/27 09:06	42864	35.38	53589	34.8335	14.5	102.3	7.46	8
EFFLUENT	2012/06/27 14:31	43361	35.43	53641	34.866	15	102.29	7.41	8
EFFLUENT	2012/06/28 09:02	42754	35.45	53693	34.8985	14.3	101.73	7.5	7.97
EFFLUENT	2012/06/28 15:02	43467	35.46	53671	34.8855	15	101.37	7.36	8.06
EFFLUENT	2012/06/29 08:58	42873	35.42	53650	34.8725	14.5	101.68	7.38	7.75
EFFLUENT	2012/06/29 10:50	43036	35.46	53687	34.8985	14.6	101.6	7.48	7.82
EFFLUENT	2012/07/02 12:45	42963	35.33	53512	34.7815	14.7	101.85	7.26	7.76
EFFLUENT	2012/07/02 14:44	42983	35.35	53543	34.801	14.7	101.78	7.2	7.82
EFFLUENT	2012/07/03 10:25	42654	35.37	53587	34.8335	14.3	101.36	7.21	7.71
EFFLUENT	2012/07/03 12:00	42822	35.38	53588	34.8335	14.5	101.26	7.47	7.85
EFFLUENT	2012/07/04 09:19	42379	35.38	53612	34.8465	14	101.87	7.67	7.74
EFFLUENT	2012/07/04 11:32	42421	35.36	53584	34.827	14.1	102.02	7.66	7.86
EFFLUENT	2012/07/05 09:30	42136	35.37	53609	34.8465	13.8	101.46	7.52	7.78
EFFLUENT	2012/07/05 11:23	42123	35.27	53465	34.7555	13.9	101.41	7.49	7.85
EFFLUENT	2012/07/06 09:42	42383	35.36	53588	34.8335	14.1	100.98	7.35	7.77
EFFLUENT	2012/07/06 12:18	42665	35.38	53591	34.8335	14.3	100.89	7.54	7.74
EFFLUENT	2012/07/09 12:19	42808	35.37	53582	34.827	14.5	102.08	7.45	7.77
EFFLUENT	2012/07/09 13:43	44466	35.44	53608	34.8465	16.1	101.96	7.07	7.82

Table C.2.3 *– Effluent 200µm water characterisation parameters as measured*

Site	Timestamp	Conductivity (uS/cm)	Salinity (ppt)	Specific Conductance (uS/cm)	TDS (g/L)	Temperature (C)	Barometric Pressure (kPa)	Dissolved Oxygen (mg/l)	pH (mg/l)
EFFLUENT 200µm	2012/03/20 15:25	48379	35.41	53536	34.80	20.0	101	7.25	8.04
EFFLUENT 200µm	2012/03/21 08:00	47742	35.38	53490	34.77	19.4	101.22	7.58	7.86
EFFLUENT 200µm	2012/03/21 09:22	47129	35.36	53460	34.75	18.8	101.3	7.03	7.86
EFFLUENT 200µm	2012/03/22 08:08	47988	35.31	53393	34.70	19.7	101.48	7.4	7.78
EFFLUENT 200µm	2012/03/22 10:08	46995	35.29	53367	34.69	18.7	101.52	6.99	7.84
EFFLUENT 200µm	2012/03/23 08:07	45879	35.24	53317	34.66	17.7	101.58	7.73	7.82
EFFLUENT 200µm	2012/03/23 10:11	45329	35.21	53278	34.63	17.2	101.65	7.57	7.81
EFFLUENT 200µm	2012/03/26 13:47	41564	35.02	53140	34.54	13.6	100.9	8.07	7.83
EFFLUENT 200µm	2012/03/26 16:04	41977	35	53099	34.52	14	100.89	8.21	7.84
EFFLUENT 200µm	2012/03/27 08:05	41049	35.03	53192	34.57	13.0	101.27	8.74	7.85
EFFLUENT 200µm	2012/03/27 10:11	41023	35.02	53177	34.57	13.0	101.3	7.98	7.82
EFFLUENT 200µm	2012/03/28 10:09	41210	35.02	53162	34.55	13.2	100.87	7.25	7.82
EFFLUENT 200µm	2012/03/29 08:14	41620	35.01	53127	34.5345	13.7	100.77	7.89	7.83
EFFLUENT 200µm	2012/03/29 10:11	42271	35.02	53114	34.5215	14.3	100.72	7.34	7.85
EFFLUENT 200µm	2012/03/30 08:16	45069	35.27	53366	34.69	16.9	101.08	7.17	7.87
EFFLUENT 200µm	2012/03/30 10:25	45382	35.29	53387	34.70	17.1	101.25	6.74	8.09
EFFLUENT 200µm	2012/04/02 13:54	44529	35.15	53214	34.59	16.5	101.86	7.55	8.04
EFFLUENT 200µm	2012/04/03 08:27	44539	35.17	53236	34.606	16.4	101.64	7.65	7.87
EFFLUENT 200µm	2012/04/03 09:40	44175	35.15	53217	34.593	16.1	101.63	6.57	7.98
EFFLUENT 200µm	2012/04/17 10:50	44151	35.14	53204	34.58	16.1	102.04	7.21	7.91
EFFLUENT 200µm	2012/04/17 16:02	44328	35.12	53177	34.567	16.3	102	7.27	7.93
EFFLUENT 200µm	2012/04/18 08:05	43516	35.13	53217	34.59	15.5	102.25	7.8	7.9
EFFLUENT 200µm	2012/04/18 12:04	43842	35.14	53218	34.59	15.8	102.23	7.04	7.99
EFFLUENT 200µm	2012/04/19 08:17	43055	35.11	53201	34.58	15	101.81	7.37	7.91
EFFLUENT 200µm	2012/04/19 10:22	43404	35.07	53137	34.541	15.4	101.81	7.39	7.94
EFFLUENT 200µm	2012/04/20 08:33	42354	35.07	53178	34.57	14.3	101.52	7.66	7.9
EFFLUENT 200µm	2012/04/20 10:42	44847	35.03	53041	34.48	16.9	101.5	7.49	7.9
EFFLUENT 200µm	2012/04/23 11:59	41915	35.02	53132	34.53	13.9	102.54	8.74	7.93
EFFLUENT 200µm	2012/04/23 14:44	43510	35.05	53103	34.52	15.5	102.38	8.49	7.97
EFFLUENT 200µm	2012/04/24 07:59	40979	35.03	53187	34.5735	13	102.41	8.78	7.91
EFFLUENT 200µm	2012/04/24 12:29	40725	34.94	53083	34.502	12.8	102.24	8.01	7.95
EFFLUENT 200µm	2012/04/25 08:04	39128	34.93	53190	34.57	11.2	101.59	8.63	7.82
EFFLUENT 200µm	2012/04/25 14:11	39309	34.93	53177	34.57	11.3	101.34	8.55	8
EFFLUENT 200µm	2012/04/26 08:50	39122	34.92	53173	34.5605	11.2	101.13	8.47	7.88
EFFLUENT 200µm	2012/04/26 13:52	39884	34.82	52968	34.4305	12.1	100.99	8	7.99
EFFLUENT 200µm	2012/05/14 11:56	46550	35.45	53593	34.8335	18.1	102.09	7.32	7.85
EFFLUENT 200µm	2012/05/14 15:37	49422	35.45	53595	34.8335	20.9	102.06	6.97	7.78
EFFLUENT 200µm	2012/05/15 08:38	44064	35.36	53511	34.7815	15.8	102.3	8.57	7.87
EFFLUENT 200µm	2012/05/15 15:38	44772	35.35	53481	34.762	16.5	102.08	7.09	7.96
EFFLUENT 200µm	2012/05/16 08:46	44310	35.34	53480	34.762	16	101.88	7.6	7.94
EFFLUENT 200µm	2012/05/16 16:10	44910	35.34	53463	34.749	16.6	101.57	7.2	7.97
EFFLUENT 200µm	2012/05/17 09:02	44136	35.32	53459	34.749	15.9	101.14	7.79	7.94
EFFLUENT 200µm	2012/05/17 13:29	44450	35.26	53360	34.684	16.3	100.8	7.4	8.01
EFFLUENT 200µm	2012/05/22 16:14	45240	35.41	53559	34.814	16.9	100.91	9.26	8.09
EFFLUENT 200µm	2012/05/23 10:18	44237	35.37	53529	34.7945	15.9	100.89	7.18	7.89
EFFLUENT 200µm	2012/05/23 10:18	44237	35.37	53529	34.7945	15.9	100.89	7.18	7.89
EFFLUENT 200µm	2012/05/24 09:04	44202	35.42	53598	34.84	15.8	101.37	7.26	7.88
EFFLUENT 200µm	2012/05/24 12:33	44645	35.43	53594	34.8335	16.3	101.36	7.46	8
EFFLUENT 200µm	2012/05/24 15:56	45077	35.43	53584	34.827	16.7	101.27	7.18	7.96
EFFLUENT 200µm	2012/05/25 09:14	44400	35.42	53586	34.8335	16	101.21	6.82	7.93
EFFLUENT 200µm	2012/05/25 12:41	44606	35.37	53510	34.7815	16.3	101.17	6.48	7.98
EFFLUENT 200µm	2012/05/28 12:10	46129	35.51	53681	34.892	17.6	101.51	6.78	8.01
EFFLUENT 200µm	2012/05/28 14:04	47225	35.52	53683	34.892	18.7	101.43	6.74	7.99
EFFLUENT 200µm	2012/05/29 08:53	45037	35.52	53714	34.9115	16.5	101.6	7.39	8.02
EFFLUENT 200µm	2012/05/29 15:24	45048	35.5	53684	34.892	16.6	101.96	6.72	8.04
EFFLUENT 200µm	2012/05/30 09:09	44848	35.52	53721	34.918	16.4	102.69	7.32	7.94
EFFLUENT 200µm	2012/05/30 15:42	46135	35.54	53712	34.9115	17.6	102.71	6.69	8.05
EFFLUENT 200µm	2012/05/31 09:06	44849	35.53	53727	34.9245	16.3	102.7	7.16	8.06
EFFLUENT 200µm	2012/05/31 14:27	45490	35.52	53707	34.9115	17	102.41	7.1	8.03
EFFLUENT 200µm	2012/06/01 09:02	44878	35.52	53708	34.9115	16.4	102.64	7.57	8
EFFLUENT 200µm	2012/06/01 11:28	45101	35.5	53677	34.892	16.6	102.7	7.13	8.08
EFFLUENT 200µm	2012/06/11 14:08	46475	35.51	53670	34.8855	18	102.25	7.49	7.97
EFFLUENT 200µm	2012/06/11 15:31	46860	35.52	53683	34.892	18.3	102.16	7.48	8
EFFLUENT 200µm	2012/06/12 08:44	44152	35.49	53691	34.8985	15.7	102.12	8.64	8.01
EFFLUENT 200µm	2012/06/12 15:55	44157	35.45	53638	34.866	15.7	102.36	7.4	8.04
EFFLUENT 200µm	2012/06/13 09:00	43709	35.48	53695	34.905	15.3	102.53	8.45	8
EFFLUENT 200µm	2012/06/13 15:05	43770	35.17	53256	34.619	15.7	102.18	7.42	8.03
EFFLUENT 200µm	2012/06/14 09:33	43253	35.44	53660	34.879	14.8	101.63	7.76	7.99
EFFLUENT 200µm	2012/06/14 15:00	44252	35.46	53647	34.8725	15.8	101.31	7.35	8.09
EFFLUENT 200µm	2012/06/15 09:07	43653	35.47	53687	34.8985	15.2	101.35	7.98	8
EFFLUENT 200µm	2012/06/15 10:48	43869	35.47	53680	34.892	15.4	101.43	7.27	8.04
EFFLUENT 200µm	2012/06/18 13:20	44559	35.43	53603	34.84	16.2	102.7	8.32	7.9
EFFLUENT 200µm	2012/06/18 16:24	43925	35.45	53648	34.8725	15.5	102.73	7.01	8
EFFLUENT 200µm	2012/06/19 08:57	42552	35.4	53625	34.853	14.2	102.61	7.66	7.91
EFFLUENT 200µm	2012/06/19 12:43	44496	35.41	53576	34.827	16.1	102.57	7.52	7.99
EFFLUENT 200µm	2012/06/20 09:47	43379	35.35	53527	34.7945	15.1	102.73	6.92	8.04
EFFLUENT 200µm	2012/06/20 15:11	43555	35.43	53633	34.8595	15.2	102.45	6.68	7.97
EFFLUENT 200µm	2012/06/21 08:56	42586	35.38	53598	34.84	14.2	101.93	7.72	7.99
EFFLUENT 200µm	2012/06/21 14:16	42985	35.37	53566	34.8205	14.7	101.52	6.77	8.02
EFFLUENT 200µm	2012/06/22 08:28	42513	35.33	53536	34.801	14.2	101.36	7.35	7.92
EFFLUENT 200µm	2012/06/22 10:17	42698	35.34	53544	34.801	14.4	101.38	6.79	7.98
EFFLUENT 200µm	2012/06/25 12:38	43711	35.32	53472	34.7555	15.4	101.55	7.1	7.96
EFFLUENT 200µm	2012/06/25 14:41	45292	35.32	53437	34.736	17	101.48	7.02	7.92
EFFLUENT 200µm	2012/06/26 09:11	43596	35.47	53687	34.8985	15.2	100.89	7.41	8.06
EFFLUENT 200µm	2012/06/26 14:15	42687	34.79	52764	34.294	15	100.98	6.79	8
EFFLUENT 200µm	2012/06/27 09:08	43262	35.44	53650	34.8725	14.9	102.31	7.27	7.97
EFFLUENT 200µm	2012/06/27 14:33	43636	35.45	53649	34.8725	15.2	102.29	6.83	7.99
EFFLUENT 200µm	2012/06/28 09:04	42735	35.45	53689	34.8985	14.3	101.72	7.39	8.01
EFFLUENT 200µm	2012/06/28 15:05	43809	35.46	53664	34.879	15.4	101.37	6.56	8.06
EFFLUENT 200µm	2012/06/29 09:01	43121	35.43	53651	34.8725	14.7	101.68	7.32	7.75
EFFLUENT 200µm	2012/06/29 10:53	43353	35.45	53670	34.8855	14.9	101.59	6.81	7.78
EFFLUENT 200µm	2012/07/02 12:47	43570	35.4	53588	34.8335	15.2	101.84	6.87	7.73
EFFLUENT 200µm	2012/07/02 14:46	43593	35.4	53589	34.8335	15.2	101.79	6.83	7.79
EFFLUENT 200µm	2012/07/03 10:27	42884	35.38	53581	34.827	14.5	101.35	7.74	7.78
EFFLUENT 200µm	2012/07/03 12:03	43947	35.38	53551	34.8075	15.6	101.26	7.72	7.79
EFFLUENT 200µm	2012/07/04 09:22	42073	35.14	53282	34.632	14	101.87	7.65	7.78
EFFLUENT 200µm	2012/07/04 11:36	42615	35.37	53586	34.8335	14.3	102.02	6.92	7.85
EFFLUENT 200µm	2012/07/05 09:33	42309	35.39	53633	34.8595	13.9	101.46	7.65	7.84
EFFLUENT 200µm	2012/07/05 11:24	42112	35.27	53469	34.7555	13.9	101.4	7.5	7.89
EFFLUENT 200µm	2012/07/06 09:44	42614	35.37	53591	34.8335	14.3	100.98	6.85	7.78
EFFLUENT 200µm	2012/07/06 12:20	42958	35.38	53582	34.827	14.6	100.89	6.76	7.77
EFFLUENT 200µm	2012/07/09 12:23	43631	35.43	53626	34.8595	15.2	102.07	7.04	7.71
EFFLUENT 200µm	2012/07/09 13:44	42899	35.39	53599	34.84	14.5	101.95	7.55	7.89

Table C.2.4 *– UF Feed water characterisation parameters as measured*

Site	Timestamp	Conductivity (uS/cm)	Salinity (ppt)	Specific Conductance (uS/cm)	TDS (g/L)	Temperature (C)	Barometric Pressure (kPa)	Dissolved Oxygen (mg/l)	pH (mg/l)
UF FEED	2012/03/20 15:35	47790	33.69	51215	33.29	21.5	100.96	7.59	7.90
UF FEED	2012/03/21 08:06	47719	35.38	53491	34.77	19.4	101.22	7.3	7.87
UF FEED	2012/03/21 09:24	47843	35.44	53566	34.82	19.4	101.3	7.52	7.87
UF FEED	2012/03/22 08:10	48643	35.35	53450	34.74	20.3	101.48	7.18	7.83
UF FEED	2012/03/22 10:10	48633	35.34	53433	34.73	20.3	101.53	7.09	7.87
UF FEED	2012/03/23 08:09	46427	35.27	53342	34.67	18.2	101.59	7.54	7.8
UF FEED	2012/03/23 10:13	46585	35.26	53330	34.66	18.4	101.65	7.57	7.82
UF FEED	2012/03/26 13:50	42779	35.02	53088	34.51	14.8	100.9	8.11	7.74
UF FEED	2012/03/26 16:06	43906	35.03	53060	34.49	16	100.89	8.02	7.82
UF FEED	2012/03/27 08:08	43942	35.03	53064	34.49	16.0	101.27	7.98	7.82
UF FEED	2012/03/27 10:14	43090	35.02	53075	34.50	15.1	101.3	7.98	7.82
UF FEED	2012/03/28 08:05	40816	35.01	53170	34.56	12.8	100.86	9.09	7.74
UF FEED	2012/03/28 10:12	41118	35	53146	34.55	13.2	100.88	7.96	7.84
UF FEED	2012/03/29 08:16	41726	35.01	53117	34.528	13.8	100.77	8.19	7.86
UF FEED	2012/03/29 10:14	42020	35.02	53123	34.528	14.1	100.72	7.73	7.86
UF FEED	2012/03/30 08:19	43873	35.16	53245	34.61	15.8	101.09	7.45	7.99
UF FEED	2012/03/30 10:27	44620	35.22	53302	34.65	16.5	101.25	7.17	8.01
UF FEED	2012/04/02 13:56	45070	35.16	53218	34.59	17	101.85	7.59	7.97
UF FEED	2012/04/03 08:29	44761	35.19	53262	34.619	16.6	101.64	7.62	7.95
UF FEED	2012/04/03 09:42	44832	35.19	53256	34.619	16.7	101.64	6.87	7.96
UF FEED	2012/04/17 10:58	43760	35.12	53195	34.5735	15.7	102.04	7.45	7.89
UF FEED	2012/04/17 16:05	45102	35.09	53115	34.5215	17.1	102	7.4	7.94
UF FEED	2012/04/18 08:08	43485	35.15	53237	34.61	15.4	102.24	7.82	7.94
UF FEED	2012/04/18 12:07	44308	35.15	53219	34.59	16.2	102.22	7.64	7.97
UF FEED	2012/04/19 08:19	43195	35.12	53214	34.5865	15.1	101.8	7.77	7.9
UF FEED	2012/04/19 10:24	43526	35.07	53127	34.5345	15.5	101.82	7.74	7.9
UF FEED	2012/04/20 08:35	42692	35.08	53181	34.57	14.7	101.52	7.74	7.91
UF FEED	2012/04/20 10:46	42983	35.05	53122	34.53	15	101.51	7.91	7.89
UF FEED	2012/04/23 12:02	41279	35.01	53152	34.55	13.3	102.54	8.72	7.96
UF FEED	2012/04/23 14:46	41622	35.02	53145	34.55	13.6	102.39	8.71	7.95
UF FEED	2012/04/24 08:00	40987	35.03	53187	34.5735	13	102.41	8.74	7.88
UF FEED	2012/04/24 12:31	41373	34.95	53060	34.489	13.5	102.25	8.39	8.03
UF FEED	2012/04/25 08:09	39367	34.94	53184	34.57	11.4	101.61	8.54	7.89
UF FEED	2012/04/25 14:13	39810	34.94	53146	34.55	11.9	101.34	8.51	7.9
UF FEED	2012/04/26 08:52	39308	34.93	53171	34.5605	11.3	101.13	8.71	7.9
UF FEED	2012/04/26 13:57	40694	34.85	52953	34.4175	12.9	100.99	8.09	7.99
UF FEED	2012/05/14 11:58	45610	35.44	53590	34.8335	17.2	102.09	7.64	7.91
UF FEED	2012/05/14 15:39	45882	35.32	53426	34.7295	17.6	102.06	7.64	7.95
UF FEED	2012/05/15 08:40	43805	35.36	53522	34.788	15.5	102.3	8.26	8.02
UF FEED	2012/05/15 10:48	44192	35.31	53442	34.74	15.9	102.29	8.18	7.93
UF FEED	2012/05/15 15:41	45582	35.36	53482	34.762	17.3	102.09	7.39	7.99
UF FEED	2012/05/16 08:48	44140	35.35	53496	34.775	15.8	101.89	7.85	7.9
UF FEED	2012/05/16 11:13	44651	35.14	53191	34.5735	16.6	101.88	8.18	8
UF FEED	2012/05/16 16:12	45641	35.34	53448	34.7425	17.4	101.58	7.32	8.06
UF FEED	2012/05/17 09:04	44001	35.31	53450	34.7425	15.7	101.15	7.72	7.88
UF FEED	2012/05/17 11:02	44195	35.29	53411	34.7165	16	101.04	8.05	7.93
UF FEED	2012/05/17 13:33	44636	35.27	53376	34.697	16.4	100.78	7.64	7.99
UF FEED	2012/05/22 16:07	42504	32.84	50058	32.539	17.1	100.9	8.43	8.01
UF FEED	2012/05/23 10:19	44048	35.37	53531	34.7945	15.7	100.89	7.64	8
UF FEED	2012/05/23 09:22	43865	35.4	53578	34.827	15.5	100.86	8.06	7.92
UF FEED	2012/05/23 12:16	44465	35.4	53563	34.814	16.1	100.88	7.34	7.92
UF FEED	2012/05/24 09:05	43922	35.43	53616	34.853	15.5	101.38	7.44	7.94
UF FEED	2012/05/24 12:36	44754	35.43	53595	34.8335	16.4	101.35	7.68	7.93
UF FEED	2012/05/24 15:57	45575	35.43	53579	34.827	17.2	101.27	7.34	7.95
UF FEED	2012/05/25 09:17	44411	35.42	53591	34.8335	16	101.2	6.98	7.93
UF FEED	2012/05/25 10:58	44758	35.38	53526	34.7945	16.4	101.19	7.42	7.89
UF FEED	2012/05/25 12:42	45382	35.38	53507	34.7815	17	101.17	7.23	8.05
UF FEED	2012/05/28 12:12	44858	35.5	53694	34.8985	16.4	101.52	7.05	7.98
UF FEED	2012/05/28 14:05	44952	35.5	53687	34.8985	16.5	101.43	7.24	7.99
UF FEED	2012/05/29 08:55	44756	35.51	53709	34.9115	16.3	101.6	7.28	8.02
UF FEED	2012/05/29 10:32	44666	35.43	53592	34.8335	16.3	101.8	7.52	8.02
UF FEED	2012/05/29 15:26	44820	35.46	53635	34.866	16.4	101.97	7.08	8.05
UF FEED	2012/05/30 09:11	44626	35.53	53736	34.931	16.1	102.69	7.22	7.98
UF FEED	2012/05/30 12:04	44915	35.53	53728	34.9245	16.4	102.78	7.87	8.18
UF FEED	2012/05/30 15:44	45944	35.53	53713	34.9115	17.4	102.72	6.96	8.02
UF FEED	2012/05/31 09:08	44661	35.53	53735	34.931	16.2	102.7	7.02	8.01
UF FEED	2012/05/31 11:03	44845	35.48	53657	34.879	16.4	102.67	7.37	7.92
UF FEED	2012/05/31 14:28	45777	35.52	53699	34.905	17.3	102.41	7.21	8.02
UF FEED	2012/06/01 09:04	44754	35.53	53731	34.9245	16.3	102.64	7.47	7.95
UF FEED	2012/06/01 11:29	45020	35.52	53706	34.9115	16.5	102.7	7.56	8.04
UF FEED	2012/06/11 14:10	43743	35.48	53689	34.8985	15.3	102.24	7.78	8.02
UF FEED	2012/06/11 15:33	43958	35.48	53681	34.892	15.5	102.16	8.07	8.09
UF FEED	2012/06/12 08:45	43771	35.49	53700	34.905	15.3	102.13	7.92	8.06
UF FEED	2012/06/12 10:43	43900	35.47	53676	34.892	15.5	102.28	8.05	8.01
UF FEED	2012/06/12 15:59	44025	35.46	53649	34.8725	15.6	102.37	7.49	8.05
UF FEED	2012/06/13 09:03	43552	35.49	53713	34.9115	15.1	102.53	7.51	8.09
UF FEED	2012/06/13 11:33	43795	35.79	54127	35.1845	15	102.45	8.43	8.07
UF FEED	2012/06/13 15:17	43920	35.47	53679	34.892	15.5	102.18	7.68	8.03
UF FEED	2012/06/14 09:36	43262	35.49	53720	34.918	14.8	101.64	7.68	7.98
UF FEED	2012/06/14 11:33	43408	35.44	53652	34.8725	15	101.57	7.93	7.41
UF FEED	2012/06/14 15:03	43582	35.48	53704	34.905	15.1	101.32	7.6	8.1
UF FEED	2012/06/15 09:09	43370	35.48	53707	34.9115	14.9	101.35	7.32	8.01
UF FEED	2012/06/15 10:50	43361	35.48	53710	34.9115	14.9	101.42	7.43	8.01
UF FEED	2012/06/18 13:22	43849	35.42	53607	34.8465	15.5	102.7	7.95	7.94
UF FEED	2012/06/18 16:29	43814	35.42	53604	34.84	15.4	102.71	8.27	7.99
UF FEED	2012/06/19 08:58	42459	35.39	53619	34.853	14.1	102.62	7.7	8.01
UF FEED	2012/06/19 10:40	42314	35.48	53750	34.9375	13.9	102.63	8.23	8.07
UF FEED	2012/06/19 12:45	42876	35.4	53612	34.8465	14.5	102.56	8.12	8.08
UF FEED	2012/06/20 09:49	43077	35.37	53563	34.814	14.7	102.72	7.47	7.99
UF FEED	2012/06/20 11:40	43378	35.33	53494	34.7685	15.1	102.69	7.8	8.05
UF FEED	2012/06/20 15:13	43598	35.41	53597	34.84	15.2	102.44	7.18	7.98
UF FEED	2012/06/21 08:58	42584	35.38	53596	34.84	14.2	101.92	7.73	7.96
UF FEED	2012/06/21 10:50	42794	35.33	53526	34.7945	14.5	101.87	8.15	8.07
UF FEED	2012/06/21 14:18	42742	35.38	53586	34.8335	14.4	101.52	7.7	8
UF FEED	2012/06/22 08:31	42380	35.33	53542	34.801	14.1	101.36	7.4	7.94
UF FEED	2012/06/22 10:19	42421	35.33	53541	34.801	14.1	101.39	7.58	8.02
UF FEED	2012/06/25 12:41	42789	35.31	53496	34.775	14.5	101.56	7.41	7.93
UF FEED	2012/06/25 14:42	44431	35.32	53453	34.7425	16.2	101.48	8.34	8.27
UF FEED	2012/06/26 09:13	43584	35.47	53684	34.892	15.2	100.88	7.42	8.05
UF FEED	2012/06/26 11:04	43809	35.46	53663	34.879	15.4	100.92	7.85	8.03
UF FEED	2012/06/26 14:17	42804	35.41	53628	34.8595	14.4	100.97	8.33	8.16
UF FEED	2012/06/27 09:10	42978	35.44	53660	34.879	14.6	102.32	7.33	8.01
UF FEED	2012/06/27 11:08	43120	35.43	53649	34.8725	14.7	102.38	7.64	7.99
UF FEED	2012/06/27 14:36	44531	35.45	53623	34.853	16.1	102.29	8.85	8.3
UF FEED	2012/06/28 09:06	42692	35.45	53690	34.8985	14.3	101.73	7.51	8.06
UF FEED	2012/06/28 10:50	42652	35.45	53694	34.8985	14.2	101.68	7.74	8.05
UF FEED	2012/06/28 15:07	43903	35.46	53661	34.879	15.5	101.37	6.99	8.05
UF FEED	2012/06/29 09:03	43023	35.43	53655	34.8725	14.6	101.68	7.46	7.76
UF FEED	2012/06/29 10:55	43175	35.44	53653	34.8725	14.8	101.59	7.58	7.75
UF FEED	2012/07/02 12:48	43310	35.4	53592	34.8335	15	101.84	7.19	7.77
UF FEED	2012/07/02 14:49	43220	35.4	53603	34.84	14.9	101.79	7.35	7.89
UF FEED	2012/07/03 10:29	42590	35.37	53585	34.8335	14.3	101.36	7.68	7.81
UF FEED	2012/07/03 12:05	42669	35.38	53593	34.8335	14.3	101.25	7.79	7.76
UF FEED	2012/07/04 09:25	41984	35.12	53270	34.6255	13.9	101.88	7.47	7.82
UF FEED	2012/07/04 11:38	42312	35.31	53508	34.7815	14	102.03	7.4	7.84
UF FEED	2012/07/05 09:37	41687	35.32	53558	34.814	13.4	101.46	7.66	7.87
UF FEED	2012/07/05 11:26	42387	35.27	53455	34.7425	14.2	101.39	6.76	7.85
UF FEED	2012/07/06 09:48	42341	35.37	53598	34.84	14	100.98	7.28	7.83
UF FEED	2012/07/06 12:23	43355	35.38	53570	34.8205	15	100.9	7.24	7.7
UF FEED	2012/07/09 12:24	43162	35.43	53645	34.8725	14.8	102.06	7.29	7.75
UF FEED	2012/07/09 13:45	43396	35.42	53626	34.8595	15	101.95	7.33	7.86

Table C.2.5 *– UF Permeate water characterisation parameters as measured*

Site	Timestamp	Conductivity (uS/cm)	Salinity (ppt)	Specific Conductance (uS/cm)	TDS (g/L)	Temperature (C)	Barometric Pressure (kPa)	Dissolved Oxygen (mg/l)	pH (mg/l)
UF PERMEATE	2012/03/20 15:28	47749	33.20	50571	32.87	22.1	100.98	6.66	7.88
UF PERMEATE	2012/03/21 08:07	47965	35.38	53491	34.77	19.6	101.24	7.45	7.86
UF PERMEATE	2012/03/21 09:28	47908	35.28	53354	34.68	19.7	101.3	7.65	7.75
UF PERMEATE	2012/03/22 08:15	48777	35.35	53448	34.74	20.4	101.49	7.2	7.82
UF PERMEATE	2012/03/22 10:12	48740	35.27	53352	34.68	20.5	101.54	7.42	7.61
UF PERMEATE	2012/03/23 08:13	46891	35.26	53335	34.66	18.7	101.59	7.43	7.78
UF PERMEATE	2012/03/23 10:15	46969	35.13	53158	34.55	18.9	101.65	7.53	7.41
UF PERMEATE	2012/03/26 13:59	44417	35.03	53053	34.48	16.5	100.89	7.88	7.67
UF PERMEATE	2012/03/26 16:08	44592	34.92	52893	34.38	16.8	100.89	8.15	7.6
UF PERMEATE	2012/03/27 08:14	44877	35.03	53035	34.47	16.9	101.28	7.91	7.82
UF PERMEATE	2012/03/27 10:17	44008	34.95	52956	34.42	16.2	101.3	8.13	7.7
UF PERMEATE	2012/03/28 08:07	41360	35.01	53146	34.55	13.4	100.85	8.58	7.79
UF PERMEATE	2012/03/28 10:14	41903	34.9	52951	34.42	14.1	100.89	3.15	6.22
UF PERMEATE	2012/03/29 08:18	42437	35.03	53112	34.5215	14.5	100.76	8.09	7.85
UF PERMEATE	2012/03/29 10:16	42543	34.72	52671	34.2355	14.9	100.72	7.95	7.34
UF PERMEATE	2012/03/30 08:21	44156	35.15	53222	34.59	16.1	101.09	7.54	7.91
UF PERMEATE	2012/03/30 10:49	40376	30.81	47280	30.73	17.4	101.28	5.37	5.39
UF PERMEATE	2012/04/02 14:03	45932	34.94	52900	34.39	18.1	101.85	7.29	7.86
UF PERMEATE	2012/04/03 08:31	45035	35.19	53256	34.619	16.9	101.64	7.61	7.94
UF PERMEATE	2012/04/03 09:45	45035	35.19	53256	34.619	16.9	101.64	7.61	7.94
UF PERMEATE	2012/04/17 11:00	44254	35.13	53190	34.5735	16.2	102.05	7.79	7.97
UF PERMEATE	2012/04/17 16:07	45167	34.98	52963	34.424	17.3	102	7.74	7.17
UF PERMEATE	2012/04/18 08:14	43744	35.15	53234	34.60	15.7	102.25	8.01	7.95
UF PERMEATE	2012/04/18 12:12	45036	35.15	53205	34.59	17	102.22	7.64	7.94
UF PERMEATE	2012/04/19 08:22	43654	35.11	53188	34.5735	15.6	101.81	7.6	7.9
UF PERMEATE	2012/04/19 10:27	44095	35.04	53074	34.50	16.1	101.81	7.82	7.94
UF PERMEATE	2012/04/20 08:38	43331	35.09	53164	34.55	15.3	101.52	7.77	7.86
UF PERMEATE	2012/04/20 10:49	43501	35.02	53064	34.49	15.6	101.5	7.9	7.28
UF PERMEATE	2012/04/23 12:04	41847	35.02	53136	34.54	13.9	102.54	8.3	7.88
UF PERMEATE	2012/04/23 14:49	41970	35.02	53124	34.53	14	102.39	8.7	7.91
UF PERMEATE	2012/04/24 08:03	41291	35.03	53169	34.5605	13.3	102.4	8.62	7.88
UF PERMEATE	2012/04/24 12:33	42390	34.92	52968	34.4305	14.5	102.24	8.44	7.96
UF PERMEATE	2012/04/25 08:11	39717	34.94	53159	34.55	11.8	101.61	8.67	7.99
UF PERMEATE	2012/04/25 14:15	40187	34.94	53118	34.53	12.3	101.32	8.41	7.91
UF PERMEATE	2012/04/26 08:54	39791	34.93	53132	34.5345	11.9	101.15	8.37	7.87
UF PERMEATE	2012/04/26 14:00	41474	34.73	52740	34.28	13.8	101.01	8.11	8
UF PERMEATE	2012/05/14 12:02	46085	35.45	53592	34.8335	17.7	102.1	7.09	7.9
UF PERMEATE	2012/05/14 15:44	46363	35.38	53492	34.7685	18	102.07	7.13	7.91
UF PERMEATE	2012/05/15 08:42	43857	35.36	53522	34.788	15.5	102.32	8.01	7.93
UF PERMEATE	2012/05/15 10:50	44253	35.37	53518	34.79	15.9	102.3	8.01	7.9
UF PERMEATE	2012/05/15 15:44	45897	35.27	53349	34.6775	17.7	102.09	7.33	7.91
UF PERMEATE	2012/05/16 08:50	44285	35.35	53496	34.775	16	101.89	7.56	7.96
UF PERMEATE	2012/05/16 11:18	44599	35.23	53323	34.658	16.4	101.89	7.5	7.9
UF PERMEATE	2012/05/16 16:16	45965	35.33	53431	34.7295	17.7	101.58	7.21	7.98
UF PERMEATE	2012/05/17 09:11	44215	35.3	53431	34.7295	16	101.16	7.58	7.92
UF PERMEATE	2012/05/17 11:14	44445	35.23	53318	34.658	16.3	101.03	7.61	7.79
UF PERMEATE	2012/05/17 13:37	45157	35.27	53362	34.684	17	100.8	7.39	7.99
UF PERMEATE	2012/05/22 16:09	42309	32.7	49868	32.4155	17.1	100.9	8.25	8.03
UF PERMEATE	2012/05/23 10:23	43977	35.36	53518	34.788	15.7	100.89	7.51	7.99
UF PERMEATE	2012/05/23 09:24	43870	35.43	53617	34.853	15.5	100.87	7.99	7.95
UF PERMEATE	2012/05/23 12:18	44379	35.21	53300	34.645	16.2	100.88	7.05	7
UF PERMEATE	2012/05/24 09:08	44110	35.42	53603	34.84	15.7	101.38	7.47	7.88
UF PERMEATE	2012/05/24 12:39	44942	35.41	53566	34.8205	16.6	101.35	7.54	7.95
UF PERMEATE	2012/05/24 16:00	45915	35.44	53578	34.827	17.5	101.26	7.35	7.95
UF PERMEATE	2012/05/25 09:18	44354	35.43	53599	34.84	16	101.22	7.25	7.93
UF PERMEATE	2012/05/25 11:00	44715	35.31	53423	34.723	16.5	101.18	7.15	6.76
UF PERMEATE	2012/05/25 12:45	45216	35.39	53534	34.7945	16.9	101.17	6.87	8.01
UF PERMEATE	2012/05/28 12:14	45102	35.51	53695	34.8985	16.6	101.51	6.64	8.03
UF PERMEATE	2012/05/28 14:16	45131	35.48	53658	34.879	16.7	101.44	7.38	7.97
UF PERMEATE	2012/05/29 08:57	44817	35.52	53710	34.9115	16.3	101.61	7.05	8
UF PERMEATE	2012/05/29 10:34	44483	35.41	53566	34.8205	16.1	101.8	7.25	7.83
UF PERMEATE	2012/05/29 15:33	44882	35.47	53639	34.866	16.5	101.98	6.97	8.04
UF PERMEATE	2012/05/30 09:13	44632	35.54	53742	34.931	16.1	102.7	6.89	7.98
UF PERMEATE	2012/05/30 12:05	44907	35.53	53730	34.9245	16.4	102.77	7.16	7.99
UF PERMEATE	2012/05/30 15:46	46203	35.54	53713	34.9115	17.7	102.73	6.69	8.01
UF PERMEATE	2012/05/31 09:11	44522	35.53	53739	34.931	16	102.69	6.77	7.95
UF PERMEATE	2012/05/31 11:16	44662	35.42	53577	34.827	16.3	102.65	7.2	7.54
UF PERMEATE	2012/05/31 14:30	45931	35.53	53712	34.9115	17.4	102.42	6.88	7.96
UF PERMEATE	2012/06/01 09:09	44660	35.53	53729	34.9245	16.2	102.65	7.23	7.92
UF PERMEATE	2012/06/01 11:34	45004	35.44	53600	34.84	16.6	102.69	7.37	6.83
UF PERMEATE	2012/06/11 14:12	43995	35.48	53681	34.892	15.6	102.25	7.38	8.02
UF PERMEATE	2012/06/11 15:49	44054	35.4	53571	34.8205	15.7	102.16	7.49	7.76
UF PERMEATE	2012/06/12 08:51	43833	35.49	53697	34.905	15.4	102.14	7.84	8.03
UF PERMEATE	2012/06/12 10:44	43972	35.41	53581	34.827	15.6	102.27	7.86	7.4
UF PERMEATE	2012/06/12 16:04	44155	35.42	53597	34.84	15.8	102.37	7.36	8.02
UF PERMEATE	2012/06/13 09:05	43459	35.43	53637	34.866	15.1	102.52	7.4	8.04
UF PERMEATE	2012/06/13 11:35	43604	35.45	53660	34.879	15.2	102.46	7.58	7.84
UF PERMEATE	2012/06/13 15:20	44290	35.49	53693	34.8985	15.8	102.18	7.44	8
UF PERMEATE	2012/06/14 09:38	43386	35.49	53713	34.9115	14.9	101.64	7.43	7.96
UF PERMEATE	2012/06/14 11:36	43493	35.45	53664	34.879	15.1	101.57	7.67	7.83
UF PERMEATE	2012/06/14 15:07	44268	35.49	53688	34.8985	15.8	101.32	7.42	8
UF PERMEATE	2012/06/15 09:11	43359	35.48	53706	34.9115	14.9	101.36	7.06	7.97
UF PERMEATE	2012/06/15 10:52	43489	35.41	53603	34.84	15.1	101.43	7.19	7.7
UF PERMEATE	2012/06/18 13:25	44300	35.43	53600	34.84	15.9	102.7	7.56	7.89
UF PERMEATE	2012/06/18 16:27	43824	35.23	53338	34.671	15.7	102.71	7.9	7.91
UF PERMEATE	2012/06/19 09:00	42598	35.4	53624	34.853	14.2	102.61	7.41	7.91
UF PERMEATE	2012/06/19 10:44	42694	35.3	53480	34.762	14.4	102.63	7.42	7.18
UF PERMEATE	2012/06/19 12:49	43368	35.38	53572	34.8205	15	102.57	7.75	7.88
UF PERMEATE	2012/06/20 09:52	44423	35.39	53553	34.8075	16.1	102.73	6.96	6.82
UF PERMEATE	2012/06/20 11:42	44253	35.34	53482	34.762	16	102.69	7.13	6.8
UF PERMEATE	2012/06/20 15:23	44986	35.43	53593	34.8335	16.6	102.46	6.61	6.9
UF PERMEATE	2012/06/21 09:11	43711	35.41	53598	34.84	15.3	101.92	7.65	6.89
UF PERMEATE	2012/06/21 10:52	43781	35.28	53418	34.723	15.6	101.89	7.47	6.79
UF PERMEATE	2012/06/21 14:20	44393	35.4	53565	34.814	16	101.51	7.42	6.83
UF PERMEATE	2012/06/22 08:33	43794	35.36	53518	34.788	15.5	101.37	7.07	6.83
UF PERMEATE	2012/06/22 10:20	43680	35.28	53413	34.7165	15.5	101.4	7.05	6.9
UF PERMEATE	2012/06/25 12:43	44360	35.34	53478	34.762	16.1	101.57	6.97	6.97
UF PERMEATE	2012/06/25 14:44	44489	35.26	53367	34.6905	16.3	101.48	7	6.96
UF PERMEATE	2012/06/26 09:16	44965	35.49	53674	34.8855	16.5	100.89	7.14	7.09
UF PERMEATE	2012/06/26 11:06	44798	35.43	53586	34.8335	16.4	100.92	7.29	6.98
UF PERMEATE	2012/06/26 14:20	44589	35.31	53437	34.736	16.3	100.96	7.01	6.89
UF PERMEATE	2012/06/27 09:13	44069	35.45	53647	34.8725	15.7	102.31	7.02	6.98
UF PERMEATE	2012/06/27 11:14	43974	35.4	53573	34.8205	15.6	102.39	7.24	7.01
UF PERMEATE	2012/06/27 14:39	45414	35.47	53631	34.8595	17	102.29	6.82	7
UF PERMEATE	2012/06/28 09:08	43282	35.46	53684	34.892	14.9	101.72	7.13	7.06
UF PERMEATE	2012/06/28 10:53	43020	35.28	53440	34.736	14.8	101.69	7.39	7.04
UF PERMEATE	2012/06/28 15:11	45471	35.49	53654	34.8725	17	101.37	6.68	7.11
UF PERMEATE	2012/06/29 09:06	44199	35.45	53636	34.866	15.8	101.69	7.22	6.95
UF PERMEATE	2012/06/29 10:57	44036	35.16	53236	34.606	16	101.6	7.05	6.68
UF PERMEATE	2012/07/02 12:51	44795	35.42	53577	34.827	16.4	101.85	6.75	6.9
UF PERMEATE	2012/07/02 15:06	44677	35.38	53531	34.7945	16.3	101.8	7.23	6.84
UF PERMEATE	2012/07/03 10:31	43585	35.39	53575	34.8205	15.2	101.36	7.35	6.88
UF PERMEATE	2012/07/03 12:05	42673	35.37	53588	34.8335	14.3	101.26	7.79	7.82
UF PERMEATE	2012/07/04 09:28	42944	35.14	53255	34.6125	14.9	101.89	7.65	7.08
UF PERMEATE	2012/07/04 11:42	43186	35.3	53467	34.7555	14.9	102.03	7.27	7.03
UF PERMEATE	2012/07/05 09:39	42478	35.33	53531	34.7945	14.2	101.46	7.48	6.81
UF PERMEATE	2012/07/05 11:29	41884	35.24	53442	34.736	13.7	101.39	7.5	7.84
UF PERMEATE	2012/07/06 09:50	43649	35.4	53588	34.8335	15.3	100.97	6.77	6.79
UF PERMEATE	2012/07/06 12:26	44622	35.4	53558	34.814	16.3	100.91	7.15	6.68
UF PERMEATE	2012/07/09 12:26	44839	35.47	53645	34.866	16.4	102.05	7.02	6.74
UF PERMEATE	2012/07/09 13:47	44716	35.39	53540	34.801	16.4	101.95	7.14	6.78

Table C.2.6 *– RO Feed water characterisation parameters as measured*

Site	Timestamp	Conductivity (uS/cm)	Salinity (ppt)	Specific Conductance (uS/cm)	TDS (g/L)	Temperature (C)	Barometric Pressure (kPa)	Dissolved Oxygen (mg/l)	pH (mg/l)
RO FEED	2012/03/20 15:44	47898	33.23	50605	32.89	22.2	100.99	7.57	7.86
RO FEED	2012/03/21 07:41	48022	35.39	53508	34.78	19.6	101.18	7.73	7.73
RO FEED	2012/03/21 09:31	47754	34.89	52835	34.35	20	101.31	7.02	7.17
RO FEED	2012/03/22 08:16	48893	35.35	53450	34.74	20.5	101.49	7.33	7.84
RO FEED	2012/03/22 10:14	46264	32.99	50267	32.68	20.8	101.54	6.55	5.47
RO FEED	2012/03/23 08:15	47276	35.27	53346	34.68	19	101.59	7.57	7.81
RO FEED	2012/03/23 10:16	41759	29.84	45932	29.85	20.2	101.66	7.09	3.54
RO FEED	2012/03/26 14:00	44947	35.02	53026	34.47	17	100.89	7.9	7.68
RO FEED	2012/03/26 16:10	41918	31.46	48163	31.30	18.2	100.88	5.2	6.11
RO FEED	2012/03/27 08:15	45000	35.02	53030	34.47	17.1	101.28	7.85	7.82
RO FEED	2012/03/27 10:20	44785	34.53	52354	34.03	17.4	101.3	7.98	7.49
RO FEED	2012/03/28 08:09	41745	35.02	53131	34.53	13.8	100.85	8.4	7.82
RO FEED	2012/03/28 10:16	42900	34.96	53000	34.45	15	100.89	2.21	6.09
RO FEED	2012/03/29 08:20	42774	35.01	53080	34.502	14.8	100.76	8.2	7.81
RO FEED	2012/03/29 10:17	43345	34.66	52561	34.164	15.8	100.73	6.1	6.56
RO FEED	2012/03/30 08:23	43902	35.09	53152	34.55	15.9	101.1	7.82	7.87
RO FEED	2012/03/30 10:51	45002	35.11	53141	34.54	17	101.28	6.57	7.96
RO FEED	2012/04/02 14:06	46616	34.94	52905	34.39	18.8	101.85	4.43	6.64
RO FEED	2012/04/03 08:33	45698	35.19	53248	34.6125	17.6	101.65	7.43	7.95
RO FEED	2012/04/03 10:41	42701	31.86	48709	31.6615	18.5	101.64	6	6.94
RO FEED	2012/04/03 15:20	47437	35	52976	34.437	19.5	101.61	7.39	7.95
RO FEED	2012/04/17 11:03	43917	34.9	52885	34.372	16.1	102.05	7.35	7.41
RO FEED	2012/04/17 16:29	42234	31.86	48718	31.668	18	102	7.31	4.13
RO FEED	2012/04/18 08:18	44237	35.15	53214	34.59	16.2	102.25	7.78	7.87
RO FEED	2012/04/18 12:17	44937	34.95	52932	34.40	17.1	102.21	7.72	7.59
RO FEED	2012/04/19 08:24	43936	35.13	53200	34.58	15.9	101.82	7.82	7.95
RO FEED	2012/04/19 10:29	44342	35.09	53128	34.53	16.3	101.82	7.85	7.85
RO FEED	2012/04/20 08:42	43686	35.07	53126	34.53	15.7	101.53	7.94	7.88
RO FEED	2012/04/20 10:51	43947	35.01	53040	34.48	16	101.5	7.93	6.69
RO FEED	2012/04/23 12:08	45915	34.98	52956	34.42	18	102.54	6.87	7.29
RO FEED	2012/04/23 14:51	42482	34.91	52946	34.42	14.7	102.38	8.4	7.84
RO FEED	2012/04/24 08:04	41458	35.03	53164	34.554	13.5	102.41	8.58	7.96
RO FEED	2012/04/24 12:35	42328	34.68	52627	34.2095	14.8	102.24	8.34	7.88
RO FEED	2012/04/25 08:14	41277	34.96	53075	34.50	13.4	101.61	8.52	7.91
RO FEED	2012/04/25 14:21	40693	34.92	53056	34.49	12.8	101.31	8.44	7.72
RO FEED	2012/04/26 09:08	40303	34.93	53100	34.515	12.4	101.15	8.8	7.84
RO FEED	2012/04/26 14:02	41718	34.84	52877	34.37	14	101.01	8.24	7.94
RO FEED	2012/05/14 12:03	46151	35.44	53584	34.827	17.7	102.1	7.35	7.9
RO FEED	2012/05/14 15:46	46264	35.36	53466	34.7555	17.9	102.07	7.42	7.88
RO FEED	2012/05/15 08:44	43777	35.35	53513	34.78	15.5	102.31	8.07	7.9
RO FEED	2012/05/15 15:46	45770	35.29	53387	34.7035	17.5	102.08	7.54	7.96
RO FEED	2012/05/16 08:52	44148	35.35	53498	34.775	15.8	101.88	7.87	7.99
RO FEED	2012/05/16 16:19	46150	35.33	53438	34.736	17.9	101.59	7.41	7.98
RO FEED	2012/05/17 09:16	44231	35.31	53447	34.7425	16	101.16	7.48	7.91
RO FEED	2012/05/17 13:39	45018	35.27	53371	34.6905	16.8	100.79	7.56	7.9
RO FEED	2012/05/24 09:11	44267	35.42	53596	34.84	15.9	101.38	7.74	7.76
RO FEED	2012/05/24 13:17	45328	35.35	53478	34.762	17	101.3	8	7.96
RO FEED	2012/05/24 16:01	46096	35.45	53593	34.8335	17.7	101.27	7.63	7.95
RO FEED	2012/05/25 10:04	44887	35.38	53518	34.788	16.6	101.17	7.39	8.05
RO FEED	2012/05/25 12:56	45323	35.42	53569	34.8205	16.9	101.18	7.37	7.9
RO FEED	2012/05/28 12:46	45198	35.51	53692	34.8985	16.7	101.49	7.14	8
RO FEED	2012/05/28 14:18	45515	35.45	53601	34.84	17.1	101.43	7.32	7.94
RO FEED	2012/05/28 15:10	45427	35.41	53552	34.8075	17.1	101.42	7.34	8
RO FEED	2012/05/29 09:23	44731	35.51	53703	34.905	16.3	101.67	7.37	8.04
RO FEED	2012/05/29 15:35	44816	35.46	53632	34.8595	16.4	101.98	7.25	7.98
RO FEED	2012/05/30 09:34	44571	35.53	53739	34.931	16.1	102.71	7.35	8.01
RO FEED	2012/05/30 15:48	46187	35.54	53715	34.918	17.7	102.73	7.13	8
RO FEED	2012/05/31 09:33	44370	35.53	53744	34.931	15.9	102.69	7.38	8.02
RO FEED	2012/05/31 14:32	45805	35.53	53704	34.905	17.3	102.42	7.06	7.99
RO FEED	2012/06/01 09:26	44630	35.53	53739	34.931	16.1	102.64	7.5	7.93
RO FEED	2012/06/01 11:00	44909	35.53	53730	34.9245	16.4	102.7	7.56	7.99
RO FEED	2012/06/11 14:47	44251	35.43	53606	34.8465	15.9	102.21	7.64	8.01
RO FEED	2012/06/11 15:52	43081	34.36	52151	33.8975	15.9	102.16	7.59	7.26
RO FEED	2012/06/12 09:05	43704	35.49	53703	34.905	15.3	102.15	7.7	8.02
RO FEED	2012/06/12 16:06	44170	35.43	53607	34.8465	15.8	102.37	7.55	8.04
RO FEED	2012/06/13 09:37	43639	35.39	53566	34.8205	15.3	102.52	7.72	8.09
RO FEED	2012/06/13 15:22	44230	35.49	53693	34.8985	15.8	102.17	7.54	8.05
RO FEED	2012/06/14 10:04	43249	35.49	53730	34.9245	14.8	101.64	7.64	7.98
RO FEED	2012/06/14 15:09	44324	35.49	53683	34.892	15.9	101.32	7.53	8.04
RO FEED	2012/06/15 10:21	43520	35.47	53685	34.8985	15.1	101.41	7.45	8.04
RO FEED	2012/06/15 11:01	43634	35.44	53638	34.866	15.2	101.43	7.82	7.91
RO FEED	2012/06/18 14:21	44784	35.43	53588	34.8335	16.4	102.69	7.53	7.99
RO FEED	2012/06/19 09:34	42353	35.4	53643	34.866	14	102.61	7.81	7.95
RO FEED	2012/06/19 12:50	43170	35.33	53504	34.775	14.9	102.56	7.79	7.74
RO FEED	2012/06/20 10:41	43970	35.41	53593	34.8335	15.6	102.74	7.49	6.88
RO FEED	2012/06/20 15:25	44974	35.42	53581	34.827	16.6	102.44	7.16	7.01
RO FEED	2012/06/21 10:20	44080	35.38	53541	34.801	15.7	101.9	7.63	7.01
RO FEED	2012/06/21 14:22	44504	35.4	53557	34.814	16.1	101.51	7.51	6.95
RO FEED	2012/06/22 09:08	44071	35.39	53550	34.8075	15.7	101.35	7.56	7
RO FEED	2012/06/22 10:35	43903	35.25	53366	34.6905	15.7	101.4	8.01	7.05
RO FEED	2012/06/25 13:16	44532	35.34	53468	34.7555	16.2	101.53	7.52	7.11
RO FEED	2012/06/25 15:13	44839	35.26	53354	34.6775	16.6	101.48	7.44	7.15
RO FEED	2012/06/26 09:57	44803	35.46	53631	34.8595	16.4	100.82	7.7	6.93
RO FEED	2012/06/26 14:21	45065	35.48	53658	34.879	16.6	100.95	7.22	7.1
RO FEED	2012/06/27 09:36	43927	35.45	53646	34.8725	15.5	102.32	7.79	7.18
RO FEED	2012/06/27 14:41	45137	35.46	53626	34.8595	16.7	102.29	7.29	7.18
RO FEED	2012/06/28 09:10	43113	35.46	53692	34.8985	14.7	101.72	7.47	7.2
RO FEED	2012/06/28 15:13	45127	35.48	53650	34.8725	16.7	101.38	7.16	7.26
RO FEED	2012/06/29 09:08	44151	35.45	53635	34.866	15.7	101.68	7.45	7
RO FEED	2012/06/29 11:12	44350	35.33	53467	34.7555	16.1	101.6	7.64	6.94
RO FEED	2012/07/02 13:43	44920	35.43	53586	34.8335	16.5	101.79	7.35	6.98
RO FEED	2012/07/02 15:07	44895	35.29	53393	34.7035	16.7	101.79	7.1	6.9
RO FEED	2012/07/03 12:18	43928	35.34	53492	34.7685	15.6	101.24	7.69	6.78
RO FEED	2012/07/04 10:40	42078	34.65	52595	34.1835	14.5	101.99	2.18	6.05
RO FEED	2012/07/04 11:44	42911	35.11	53201	34.58	14.9	102.02	6.4	6.78
RO FEED	2012/07/04 14:21	43765	35.38	53555	34.8075	15.4	102	7.63	7.25
RO FEED	2012/07/04 15:32	43929	35.44	53625	34.853	15.5	101.98	7.69	7.1
RO FEED	2012/07/05 10:27	41885	35.22	53405	34.71	13.7	101.45	7.88	6.91
RO FEED	2012/07/05 11:31	43022	35.26	53410	34.7165	14.8	101.34	7.84	7.13
RO FEED	2012/07/05 12:59	43253	35.24	53380	34.697	15.1	101.26	7.82	6.91
RO FEED	2012/07/06 10:13	43505	35.4	53593	34.8335	15.1	100.97	7.64	6.98
RO FEED	2012/07/06 12:28	44687	35.39	53542	34.801	16.3	100.91	7.48	6.97
RO FEED	2012/07/09 12:28	44953	35.46	53636	34.866	16.5	102.04	7.28	6.83
RO FEED	2012/07/09 13:19	45070	35.49	53663	34.879	16.6	101.96	7.74	6.8

Table C.2.7 *– RO Permeate water characterisation parameters as measured*

Site	Timestamp	Conductivity (uS/cm)	Salinity (ppt)	Specific Conductance (uS/cm)	TDS (g/L)	Temperature (C)	Barometric Pressure (kPa)	Dissolved Oxygen (mg/l)	pH (mg/l)
RO PERMEATE	2012/03/20 15:31	2100	0.98	1948	1.27	29.1	100.97	7.63	7.57
RO PERMEATE	2012/03/21 07:43	2174	1.06	2087	1.36	27.2	101.18	7.96	7.82
RO PERMEATE	2012/03/21 09:50	2066	1.01	1996	1.30	26.8	101.33	8.14	7.75
RO PERMEATE	2012/03/22 08:18	1928	0.93	1845	1.20	27.4	101.49	7.72	7.87
RO PERMEATE	2012/03/22 10:35	2120	1.01	2003	1.30	28.1	101.52	6.41	5.64
RO PERMEATE	2012/03/23 08:25	1899	0.94	1855	1.20	26.2	101.59	8.19	7.66
RO PERMEATE	2012/03/23 10:25	1835	0.89	1761	1.14	27.2	101.67	7.98	5.92
RO PERMEATE	2012/03/26 14:11	2020	1	1967	1.28	26.4	100.88	8.28	7.83
RO PERMEATE	2012/03/26 16:24	1647	0.8	1601	1.04	26.5	100.9	5.23	5.81
RO PERMEATE	2012/03/27 08:22	2095	1.08	2122	1.38	24.3	101.28	8.58	7.76
RO PERMEATE	2012/03/27 10:27	1784	0.88	1740	1.13	26.3	101.31	8.25	7.22
RO PERMEATE	2012/03/28 08:16	1713	0.91	1787	1.16	22.8	100.87	9.02	7.25
RO PERMEATE	2012/03/28 10:22	1768	0.91	1797	1.17	24.2	100.89	6.01	5.63
RO PERMEATE	2012/03/29 08:34	1650	0.85	1684	1.092	23.9	100.78	6.96	7.15
RO PERMEATE	2012/03/29 10:32	1623	0.82	1626	1.0595	24.9	100.7	4.48	5.58
RO PERMEATE	2012/03/30 08:32	1879	0.95	1869	1.22	25.3	101.11	6.79	6.97
RO PERMEATE	2012/03/30 11:06	1586	0.8	1594	1.03	24.7	101.3	6.28	5.9
RO PERMEATE	2012/04/02 14:23	1965	0.94	1870	1.22	27.7	101.85	3.11	5.92
RO PERMEATE	2012/04/03 08:42	1807	0.91	1800	1.17	25.2	101.65	7.76	7.76
RO PERMEATE	2012/04/03 10:38	1563	0.77	1538	1.001	25.9	101.64	5.79	6.84
RO PERMEATE	2012/04/03 15:19	2174	1.04	2052	1.3325	28.1	101.61	7.76	7.04
RO PERMEATE	2012/04/17 11:10	1769	0.91	1802	1.17	24	102.06	7.71	7.78
RO PERMEATE	2012/04/17 16:30	1909	0.95	1886	1.2285	25.6	102.01	7.81	6.39
RO PERMEATE	2012/04/18 08:27	1637	0.86	1696	1.11	23.2	102.28	8.37	7.43
RO PERMEATE	2012/04/18 12:20	1768	0.88	1745	1.14	25.7	102.21	8.18	6.7
RO PERMEATE	2012/04/19 08:32	1557	0.8	1598	1.04	23.6	101.83	8.37	7.24
RO PERMEATE	2012/04/19 10:36	1639	0.83	1651	1.07	24.6	101.8	8.33	6.53
RO PERMEATE	2012/04/20 08:46	1717	0.89	1753	1.14	23.9	101.54	8.19	7.27
RO PERMEATE	2012/04/20 10:58	1699	0.86	1701	1.11	24.9	101.52	8.26	5.69
RO PERMEATE	2012/04/23 12:16	1878	0.95	1877	1.22	25	102.55	7.13	6.49
RO PERMEATE	2012/04/23 14:59	1630	0.85	1679	1.09	23.5	102.37	8.55	6.97
RO PERMEATE	2012/04/24 08:06	1437	0.78	1538	1.001	21.6	102.41	9.15	7.58
RO PERMEATE	2012/04/24 12:38	1583	0.82	1629	1.0595	23.5	102.23	8.65	6.96
RO PERMEATE	2012/04/25 08:27	1659	0.95	1868	1.22	19.1	101.61	9.74	7.4
RO PERMEATE	2012/04/25 14:30	1659	0.9	1781	1.16	21.4	101.31	9.21	6.65
RO PERMEATE	2012/04/26 09:11	1436	0.79	1563	1.014	20.7	101.14	9.21	7.12
RO PERMEATE	2012/04/26 14:17	1568	0.82	1619	1.05	23.4	101.04	8.87	7.19
RO PERMEATE	2012/05/14 12:16	2002	1	1964	1.274	26	102.11	7.48	7.59
RO PERMEATE	2012/05/14 16:01	1666	0.84	1667	1.0855	25	102.08	7.91	6.53
RO PERMEATE	2012/05/15 09:00	1435	0.77	1526	0.99	21.9	102.33	8.64	7.7
RO PERMEATE	2012/05/15 16:01	1685	0.85	1679	1.092	25.2	102.1	7.94	7.33
RO PERMEATE	2012/05/16 09:20	1478	0.78	1548	1.0075	22.6	101.9	8.46	7.25
RO PERMEATE	2012/05/16 16:31	1849	0.92	1824	1.183	25.7	101.58	7.84	7.42
RO PERMEATE	2012/05/17 09:30	1427	0.75	1494	0.9685	22.7	101.15	8.3	7.68
RO PERMEATE	2012/05/17 13:56	1616	0.83	1648	1.0725	24	100.79	8.21	6.99
RO PERMEATE	2012/05/24 09:25	1519	0.79	1561	1.014	23.6	101.39	7.97	7.67
RO PERMEATE	2012/05/24 13:18	1648	0.83	1643	1.066	25.2	101.3	8.45	7.6
RO PERMEATE	2012/05/24 16:03	1654	0.83	1646	1.0725	25.2	101.27	8.45	7.34
RO PERMEATE	2012/05/25 10:00	1627	0.84	1672	1.0855	23.6	101.18	7.92	6.97
RO PERMEATE	2012/05/25 13:04	1544	0.79	1574	1.0205	24	101.2	7.82	7.06
RO PERMEATE	2012/05/28 13:00	1553	0.79	1565	1.014	24.6	101.49	7.57	7.39
RO PERMEATE	2012/05/28 14:28	1589	0.8	1600	1.04	24.7	101.43	7.73	7.15
RO PERMEATE	2012/05/28 15:24	1543	0.78	1556	1.014	24.6	101.42	7.78	7.23
RO PERMEATE	2012/05/29 09:32	1488	0.77	1541	1.001	23.2	101.68	7.78	7.33
RO PERMEATE	2012/05/29 15:52	1464	0.76	1512	0.9815	23.4	102	7.94	6.9
RO PERMEATE	2012/05/30 09:36	1506	0.78	1559	1.014	23.2	102.72	7.89	7.31
RO PERMEATE	2012/05/30 16:08	1606	0.8	1597	1.04	25.3	102.75	7.82	7.31
RO PERMEATE	2012/05/31 09:35	1432	0.75	1489	0.9685	23	102.7	7.78	7.3
RO PERMEATE	2012/05/31 14:34	1552	0.78	1557	1.014	24.8	102.41	7.73	7.14
RO PERMEATE	2012/06/01 09:31	1457	0.76	1506	0.9815	23.3	102.66	8.05	6.91
RO PERMEATE	2012/06/01 11:02	1715	0.89	1654	1.1375	23.8	102.7	7.92	7.29
RO PERMEATE	2012/06/11 14:42	1480	0.77	1528	0.9945	23.4	102.2	7.96	6.89
RO PERMEATE	2012/06/11 16:00	1444	0.75	1490	0.9685	23.4	102.16	7.77	6.82
RO PERMEATE	2012/06/12 09:12	1432	0.75	1495	0.9685	22.8	102.16	8.17	6.99
RO PERMEATE	2012/06/12 16:22	1457	0.76	1513	0.9815	23.1	102.37	8.17	7
RO PERMEATE	2012/06/13 09:35	1393	0.75	1484	0.962	21.8	102.52	8.41	6.87
RO PERMEATE	2012/06/13 15:42	1467	0.77	1522	0.988	23.1	102.18	8.25	6.99
RO PERMEATE	2012/06/14 10:28	1422	0.75	1497	0.975	22.4	101.63	8.21	7
RO PERMEATE	2012/06/14 15:28	1530	0.79	1563	1.014	23.9	101.32	7.97	7.03
RO PERMEATE	2012/06/15 10:16	1459	0.78	1543	1.001	22.1	101.41	8.09	6.89
RO PERMEATE	2012/06/15 11:21	1512	0.79	1566	1.0205	23.2	101.42	8.15	6.82
RO PERMEATE	2012/06/18 14:30	1567	0.81	1616	1.053	23.4	102.69	7.96	6.75
RO PERMEATE	2012/06/19 09:37	1364	0.74	1464	0.949	21.4	102.61	8.22	6.82
RO PERMEATE	2012/06/19 12:52	1476	0.76	1522	0.988	23.4	102.56	7.97	7.05
RO PERMEATE	2012/06/20 11:02	1441	0.76	1511	0.9815	22.6	102.73	8.19	5.93
RO PERMEATE	2012/06/20 15:47	1508	0.78	1550	1.0075	23.6	102.45	8.17	6.01
RO PERMEATE	2012/06/21 10:16	1456	0.77	1521	0.988	22.7	101.89	8.27	6.01
RO PERMEATE	2012/06/21 14:37	1505	0.77	1540	1.001	23.8	101.51	8.37	6.42
RO PERMEATE	2012/06/22 09:04	1400	0.73	1462	0.949	22.8	101.36	8.15	6.16
RO PERMEATE	2012/06/22 10:53	1434	0.74	1481	0.962	23.3	101.42	8.39	6.16
RO PERMEATE	2012/06/25 13:34	1461	0.75	1493	0.9685	23.9	101.5	7.99	6.18
RO PERMEATE	2012/06/25 15:14	1430	0.73	1465	0.9555	23.7	101.48	8.23	6.06
RO PERMEATE	2012/06/26 10:16	1384	0.73	1457	0.949	22.4	100.86	8.03	6.1
RO PERMEATE	2012/06/26 14:40	1405	0.74	1465	0.949	22.9	100.94	8.11	6.1
RO PERMEATE	2012/06/27 09:57	1361	0.72	1430	0.9295	22.5	102.36	8.13	6.07
RO PERMEATE	2012/06/27 15:00	1435	0.73	1463	0.949	24	102.27	8.16	6.11
RO PERMEATE	2012/06/28 09:27	1297	0.69	1383	0.897	21.7	101.7	8.63	6.07
RO PERMEATE	2012/06/28 15:29	1424	0.73	1449	0.9425	24.1	101.38	8.12	6.22
RO PERMEATE	2012/06/29 09:31	1381	0.73	1447	0.9425	22.6	101.67	8.13	6.14
RO PERMEATE	2012/06/29 11:25	1421	0.73	1464	0.949	23.5	101.59	8.09	6.23
RO PERMEATE	2012/07/02 14:02	1466	0.75	1497	0.975	23.9	101.78	8.14	6.21
RO PERMEATE	2012/07/02 15:20	1504	0.77	1531	0.9945	24.1	101.8	8.02	6.07
RO PERMEATE	2012/07/04 11:06	1553	0.84	1664	1.079	21.5	102.01	4.09	5.4
RO PERMEATE	2012/07/04 12:13	1532	0.82	1629	1.0595	21.9	102.02	6.53	5.75
RO PERMEATE	2012/07/04 14:42	1648	0.88	1733	1.1245	22.4	102.01	8.39	6.24
RO PERMEATE	2012/07/04 15:53	1516	0.8	1578	1.027	22.9	102	8.35	6.11
RO PERMEATE	2012/07/05 10:45	1325	0.73	1445	0.936	20.6	101.46	8.7	5.9
RO PERMEATE	2012/07/05 12:05	1370	0.73	1460	0.949	21.8	101.34	8.67	5.99
RO PERMEATE	2012/07/05 13:11	1473	0.77	1540	1.001	22.7	101.24	8.18	6.01
RO PERMEATE	2012/07/06 10:39	1390	0.73	1458	0.949	22.6	100.98	8.21	5.85
RO PERMEATE	2012/07/06 12:48	1487	0.75	1502	0.975	24.5	100.87	8.19	5.99
RO PERMEATE	2012/07/09 12:49	1387	0.72	1439	0.936	23.1	102.01	8.38	5.93
RO PERMEATE	2012/07/09 13:35	1411	0.73	1451	0.9425	23.6	101.96	8.44	6

Table C.2.8 *– RO Concentrate water characterisation parameters as measured*

Site	Timestamp	Conductivity (uS/cm)	Salinity (ppt)	Specific Conductance (uS/cm)	TDS (g/L)	Temperature (C)	Barometric Pressure (kPa)	Dissolved Oxygen (mg/l)	pH (mg/l)
RO CONCENTRATE	2012/03/20 15:43	93293	58.71	83721	54.41	31.0	100.98	5.60	7.69
RO CONCENTRATE	2012/03/21 07:53	96157	62.64	88401	57.46	29.6	101.22	5.36	7.69
RO CONCENTRATE	2012/03/21 09:42	93859	61.3	86770	56.42	29.3	101.3	4.35	7.15
RO CONCENTRATE	2012/03/22 08:29	96165	63.34	89210	57.98	29.1	101.48	4.97	7.67
RO CONCENTRATE	2012/03/22 10:43	91838	59.15	84187	54.73	29.8	101.50	4.24	6.1
RO CONCENTRATE	2012/03/23 08:35	94158	62.38	88039	57.20	28.6	101.61	5.44	7.65
RO CONCENTRATE	2012/03/23 10:32	90159	58.67	83570	54.34	29.1	101.67	5.19	3.5
RO CONCENTRATE	2012/03/26 14:21	97744	65.04	91218	59.28	28.7	100.88	5.52	7.58
RO CONCENTRATE	2012/03/26 16:34	85939	56.95	81406	52.91	27.9	100.9	1.42	6.3
RO CONCENTRATE	2012/03/27 08:27	88034	59.69	84709	55.06	27.1	101.28	5.79	7.67
RO CONCENTRATE	2012/03/27 10:33	89191	60.11	85233	55.38	27.4	101.33	5.88	7.44
RO CONCENTRATE	2012/03/28 08:23	83645	61.28	86527	56.23	23.3	100.86	6.17	7.68
RO CONCENTRATE	2012/03/28 10:28	87763	61.54	86896	56.49	25.5	100.89	1.82	6.13
RO CONCENTRATE	2012/03/29 08:45	88630	62.59	88145	57.265	25.3	100.79	4.96	7.7
RO CONCENTRATE	2012/03/29 10:43	83971	57.55	82070	53.365	26.2	100.71	0.43	6.24
RO CONCENTRATE	2012/03/30 09:00	98067	69.03	95819	62.27	26.2	101.12	4.43	7.73
RO CONCENTRATE	2012/03/30 11:04	87712	60.75	85962	55.90	26.1	101.3	2.28	6.54
RO CONCENTRATE	2012/04/02 14:25	93399	61.86	87410	56.81	28.6	101.86	2.1	6.93
RO CONCENTRATE	2012/04/03 08:39	89450	61.77	87203	56.68	26.3	101.66	5.23	7.74
RO CONCENTRATE	2012/04/03 10:37	83598	55.96	80158	52.13	27.2	101.64	3.39	6.89
RO CONCENTRATE	2012/04/03 15:17	95792	63.37	89227	57.98	28.9	101.59	4.7	7.75
RO CONCENTRATE	2012/04/17 11:11	86930	61.13	86398	56.16	25.3	102.06	4.68	7.08
RO CONCENTRATE	2012/04/17 16:31	89965	61.53	86930	56.485	26.8	102.02	4.65	7.14
RO CONCENTRATE	2012/04/18 08:28	85655	61.36	86642	56.29	24.4	102.27	5.69	7.66
RO CONCENTRATE	2012/04/18 12:21	89757	61.45	86825	56.42	26.8	102.2	5.5	7.42
RO CONCENTRATE	2012/04/19 08:33	86266	61.03	86261	56.095	25	101.83	5.76	7.67
RO CONCENTRATE	2012/04/19 10:38	88054	61.51	86866	56.49	25.7	101.79	5.76	7.59
RO CONCENTRATE	2012/04/20 08:46	84194	59.13	83964	54.60	25.1	101.54	5.72	7.58
RO CONCENTRATE	2012/04/20 11:00	88147	61.11	86391	56.16	26.1	101.51	5.73	6.75
RO CONCENTRATE	2012/04/23 12:18	87571	60.69	85887	55.84	26	102.54	4.71	7.19
RO CONCENTRATE	2012/04/23 15:01	85814	61.32	86601	56.29	24.5	102.37	5.87	7.51
RO CONCENTRATE	2012/04/24 08:07	85431	63.51	89205	57.98	22.8	102.41	6.14	7.57
RO CONCENTRATE	2012/04/24 12:39	85679	60.98	86197	56.03	24.7	102.23	5.97	7.75
RO CONCENTRATE	2012/04/25 08:28	78824	61.38	86654	56.36	20.3	101.6	6.39	7.79
RO CONCENTRATE	2012/04/25 14:31	82493	61.05	86245	56.03	22.7	101.31	6.24	7.61
RO CONCENTRATE	2012/04/26 09:13	81635	61.18	86391	56.16	22.1	101.14	6.16	7.76
RO CONCENTRATE	2012/04/26 14:19	85244	60.8	85973	55.90	24.6	101.04	6.01	7.76
RO CONCENTRATE	2012/05/14 12:17	94251	64.51	90516	58.825	27.2	102.11	5.13	7.74
RO CONCENTRATE	2012/05/14 16:03	88506	60.88	86126	55.965	26.4	102.08	5.44	7.6
RO CONCENTRATE	2012/05/15 09:02	83684	61.12	86340	56.10	23.4	102.34	5.81	7.85
RO CONCENTRATE	2012/05/15 16:03	89118	61.09	86389	56.16	26.7	102.09	5.47	7.8
RO CONCENTRATE	2012/05/16 09:21	85735	61.26	86527	56.225	24.5	101.89	5.65	7.78
RO CONCENTRATE	2012/05/16 16:33	89771	61.09	86405	56.16	27	101.57	5.22	7.86
RO CONCENTRATE	2012/05/17 09:31	86267	61.65	86996	56.55	24.6	101.15	5.5	7.73
RO CONCENTRATE	2012/05/17 14:00	86766	61	86236	56.03	25.3	100.8	5.48	7.8
RO CONCENTRATE	2012/05/24 09:28	85863	60.84	86025	55.9	24.9	101.4	5.56	7.79
RO CONCENTRATE	2012/05/24 13:20	88418	60.93	86187	56.03	26.4	101.3	5.79	7.76
RO CONCENTRATE	2012/05/24 16:04	89130	61.45	86819	56.42	26.4	101.27	5.72	7.76
RO CONCENTRATE	2012/05/25 10:02	86910	61.53	86866	56.485	25	101.18	5.3	7.79
RO CONCENTRATE	2012/05/25 13:09	87294	61.43	86757	56.42	25.3	101.19	5.35	7.75
RO CONCENTRATE	2012/05/28 13:02	87182	60.92	86153	56.03	25.6	101.48	5.24	7.83
RO CONCENTRATE	2012/05/28 14:31	87845	61.07	86339	56.095	25.9	101.44	5.3	7.75
RO CONCENTRATE	2012/05/28 15:28	88261	61.46	86807	56.42	25.9	101.42	5.26	7.8
RO CONCENTRATE	2012/05/29 09:36	85654	61.36	86648	56.29	24.4	101.69	5.29	7.89
RO CONCENTRATE	2012/05/29 15:54	85759	61.12	86358	56.16	24.6	102	5.47	7.91
RO CONCENTRATE	2012/05/30 09:39	85319	60.86	86041	55.9	24.6	102.72	5.44	7.86
RO CONCENTRATE	2012/05/30 16:10	89233	61.18	86503	56.225	26.7	102.74	5.32	7.82
RO CONCENTRATE	2012/05/31 09:38	85358	61.22	86471	56.225	24.3	102.69	5.35	7.81
RO CONCENTRATE	2012/05/31 14:36	88696	61.33	86661	56.355	26.2	102.42	5.32	7.81
RO CONCENTRATE	2012/06/01 09:34	85474	60.9	86098	55.965	24.6	102.66	5.52	7.86
RO CONCENTRATE	2012/06/01 11:03	85648	60.92	86123	55.965	24.7	102.7	5.35	7.83
RO CONCENTRATE	2012/06/11 14:44	85815	61.07	86297	56.095	24.7	102.2	5.36	7.84
RO CONCENTRATE	2012/06/11 16:02	82887	58.81	83556	54.34	24.6	102.15	5.42	7.43
RO CONCENTRATE	2012/06/12 09:15	84951	61.08	86300	56.095	24.2	102.17	5.47	7.86
RO CONCENTRATE	2012/06/12 16:25	85476	61.07	86298	56.095	24.5	102.37	5.46	7.89
RO CONCENTRATE	2012/06/13 09:41	82980	61.07	86272	56.095	23	102.52	5.63	7.91
RO CONCENTRATE	2012/06/13 15:44	85151	61	86204	56.03	24.4	102.18	5.53	7.92
RO CONCENTRATE	2012/06/14 10:30	84479	61.13	86362	56.16	23.9	101.63	5.51	7.92
RO CONCENTRATE	2012/06/14 15:31	87238	61.13	86400	56.16	25.5	101.32	5.36	7.87
RO CONCENTRATE	2012/06/15 10:19	83951	60.9	86070	55.965	23.7	101.4	5.41	7.87
RO CONCENTRATE	2012/06/15 11:24	85414	60.87	86055	55.965	24.6	101.42	5.46	7.8
RO CONCENTRATE	2012/06/18 14:35	85898	60.94	86143	55.965	24.9	102.69	5.37	7.85
RO CONCENTRATE	2012/06/19 09:40	82524	60.73	85862	55.835	23	102.61	5.51	7.89
RO CONCENTRATE	2012/06/19 12:54	84847	60.64	85781	55.77	24.4	102.55	5.51	7.7
RO CONCENTRATE	2012/06/20 11:05	84002	60.81	85967	55.9	23.8	102.73	5.46	7.11
RO CONCENTRATE	2012/06/20 15:49	86433	61.06	86305	56.095	25.1	102.45	5.39	7.25
RO CONCENTRATE	2012/06/21 10:18	84687	60.86	86041	55.9	24.2	101.89	5.56	7.27
RO CONCENTRATE	2012/06/21 14:39	86640	60.93	86154	56.03	25.3	101.5	5.41	7.24
RO CONCENTRATE	2012/06/22 09:06	84649	60.78	85938	55.835	24.2	101.36	5.43	7.19
RO CONCENTRATE	2012/06/22 10:58	85733	60.88	86080	55.965	24.8	101.41	5.41	7.26
RO CONCENTRATE	2012/06/25 13:36	86657	61.03	86264	56.095	25.2	101.49	5.29	7.31
RO CONCENTRATE	2012/06/25 15:16	86062	60.68	85843	55.77	25.1	101.48	5.42	7.31
RO CONCENTRATE	2012/06/26 10:18	84423	61.09	86303	56.095	23.9	100.86	5.37	7.34
RO CONCENTRATE	2012/06/26 14:44	85057	61.15	86386	56.16	24.2	100.95	5.33	7.3
RO CONCENTRATE	2012/06/27 09:59	84328	60.92	86104	55.965	23.9	102.35	5.36	7.34
RO CONCENTRATE	2012/06/27 15:06	86990	61.05	86299	56.095	25.4	102.28	5.41	7.39
RO CONCENTRATE	2012/06/28 09:30	83265	61.14	86362	56.16	23.1	101.71	5.53	7.41
RO CONCENTRATE	2012/06/28 15:33	86774	60.9	86114	55.965	25.4	101.37	5.31	7.41
RO CONCENTRATE	2012/06/29 09:33	84589	60.92	86110	55.965	24.1	101.66	5.47	7.19
RO CONCENTRATE	2012/06/29 11:28	85974	60.85	86047	55.9	25	101.59	5.43	7.13
RO CONCENTRATE	2012/07/02 14:04	86903	61.18	86455	56.225	25.3	101.79	5.22	7.17
RO CONCENTRATE	2012/07/02 15:22	87128	61.03	86283	56.095	25.5	101.8	5.29	7.1
RO CONCENTRATE	2012/07/04 11:08	81109	59.72	84634	54.99	22.8	102.02	0.15	6.16
RO CONCENTRATE	2012/07/04 12:15	83683	60.97	86157	56.03	23.5	102.02	4.22	6.99
RO CONCENTRATE	2012/07/04 14:44	84949	61.22	86467	56.225	24.1	102	5.49	7.3
RO CONCENTRATE	2012/07/04 15:55	84969	60.8	85971	55.9	24.4	102.01	5.42	7.25
RO CONCENTRATE	2012/07/05 10:47	81079	60.55	85637	55.64	22.2	101.47	5.78	7.13
RO CONCENTRATE	2012/07/05 11:59	82960	60.97	86154	56.03	23.1	101.34	5.66	7.22
RO CONCENTRATE	2012/07/05 13:13	84988	60.91	86103	55.965	24.3	101.24	5.43	7.19
RO CONCENTRATE	2012/07/06 10:41	84098	60.89	86066	55.965	23.8	100.96	5.45	7.11
RO CONCENTRATE	2012/07/06 12:51	87583	61.09	86358	56.16	25.7	100.86	5.47	7.21
RO CONCENTRATE	2012/07/09 12:51	85523	61.14	86376	56.16	24.5	102.01	5.41	7.09
RO CONCENTRATE	2012/07/09 13:37	86372	61.17	86430	56.16	25	101.95	5.37	7.07

Table C.2.9 *– Turbidity as measured for the influent, effluent, effluent200µm, UF permeate, and RO permeate streams*

DATE	INFLUENT	EFFLUENT	EFFLUENT200 µm	UF PERMEATE	RO PERMEATE
2011/10/17	0.31	0.41		0.10	
2011/10/18	0.23	0.41		0.10	
2011/11/08	0.87	0.64		0.14	
2011/11/09	1.34	0.63		0.17	
2011/11/10	0.72	0.71		0.10	
2011/11/10	0.78	0.49		0.09	
2011/11/16	0.26	0.28		0.05	
2011/11/16	0.23	0.30		0.11	
2011/11/16	0.22	0.30		0.11	
2011/11/17	0.27	0.37		0.09	
2011/11/29	0.33	0.29		0.08	
2011/11/30	0.25	0.29		0.05	
2012/01/17	0.51	0.38		0.12	
2012/01/24	0.58	0.46		0.07	
2012/02/07	0.91	0.49		0.08	
2012/02/16	0.78	0.48		0.11	
2012/02/23	0.98	0.50	0.53	0.06	0.06
2012/02/29	0.72	0.60	0.62	0.07	0.06
2012/03/07	1.24	0.63	0.61	0.08	0.04
2012/03/23	1.20	0.82	0.97	0.05	0.05
2012/03/28	0.68	0.41	0.48	0.09	0.08
2012/04/18	1.93	0.56	0.55	0.13	0.08
2012/04/23	1.11	0.65	0.68	0.07	0.06
2012/05/02	0.92	0.39	0.53	0.06	0.09
2012/05/03	1.22	0.42	0.47	0.07	0.08
2012/05/04	1.28	0.60	0.66	0.06	0.09
2012/05/08	0.86	0.61	0.65	0.08	0.07
2012/05/10	0.56	0.43	0.49	0.06	0.06
2012/05/09	1.40	0.51	0.60	0.08	0.07
2012/05/15	0.62	0.37	0.48	0.08	0.06
2012/05/16	0.83	0.42	0.48	0.07	0.06
2012/05/17	0.97	0.51	0.65	0.06	0.05
2012/05/29	0.49	0.34	0.43	0.05	0.06
2012/05/30	0.46	0.37	0.40	0.06	0.05
2012/05/31	0.86	0.61	0.54	0.05	0.05
2012/06/05	0.51	0.54	0.48	0.05	0.06
2012/06/06	0.51	0.41	0.53	0.06	0.06
2012/06/07	1.24	0.59	0.57	0.06	0.06
2012/06/12	0.64	0.37	0.44	0.06	0.06
2012/06/13	0.83	0.45	0.52	0.06	0.06
2012/06/14	0.95	0.52	0.57	0.06	0.05
2012/06/19	0.95	0.54	0.75	0.07	0.05
2012/06/20	0.84	0.41	0.49	0.06	0.06
2012/06/21	2.17	0.50	0.59	0.06	0.06
2012/06/26	0.54	0.42	0.52	0.05	0.06
2012/06/27	1.84	0.35	0.42	0.06	0.05
2012/06/28	0.72	0.36	0.33	0.06	0.05

Table C.2.10a *– MFI as Measured for the influent and effluent streams*

DATE	INFLUENT MFI (s/L^2)	EFFLUENT MFI (s/L^2)	MEMBRANE
2011/11/01	**17.10**	**34.58**	HVLP04700
2011/11/01	**15.26**	**50.66**	HVLP04700
2011/11/02	**15.81**	**31.45**	HVLP04700
2011/11/02	**27.87**	**32.48**	HVLP04700
2011/11/10	**29.30**	**30.20**	HVLP04700
2011/11/17	**14.55**	**15.93**	HVLP04700
2011/11/28	**17.12**	**13.65**	HVLP04700
2011/11/29	**16.71**	**16.18**	HVLP04700
2012/01/19	**23.21**	**34.34**	HVLP04700
2012/02/24	**95.74**	**161.02**	HVLP04702
2012/03/02	**72.11**	**107.35**	HAWG047S6
2012/04/20	**38.71**	**59.21**	HAWG047S6
2012/04/25	**50.13**	**50.66**	HAWG047S6
2012/05/02	**23.03**	**31.91**	HAWG047S6
2012/05/03	**30.83**	**53.46**	HAWG047S6
2012/05/08	**41.55**	**47.64**	HAWG047S6
2012/05/09	**24.89**	**48.89**	HAWG047S6
2012/05/10	**33.96**	**59.85**	HVLP04702
2012/05/15	**18.97**	**54.09**	HAWG047S6
2012/05/16	**29.39**	**61.37**	HVLP04702
2012/05/17	**21.04**	**61.55**	HAWG047S6
2012/05/29	**12.48**	**42.57**	HAWG047S6
2012/05/30	**22.78**	**41.70**	HAWG047S6
2012/05/31	**30.40**	**59.36**	HAWG047S6
2012/06/05	**23.51**	**64.04**	HAWG047S6
2012/06/06	**30.97**	**63.39**	HAWG047S6
2012/06/07	**44.62**	**57.01**	HAWG047S6
2012/06/12	**14.79**	**34.86**	HAWG047S6
2012/06/13	**28.07**	**39.61**	HAWG047S6
2012/06/14	**27.11**	**39.08**	HAWG047S6
2012/06/20	**21.42**	**35.39**	HAWG047S6
2012/06/21	**32.29**	**36.36**	HAWG047S6
2012/06/26	**13.23**	**33.48**	HAWG047S6
2012/06/27	**32.13**	**31.03**	HAWG047S6
2012/06/28	**15.50**	**34.87**	HAWG047S6

Table C.2.10b *– MFI sample calculation table*

date	**28/06/2012**
time	**28/06/2012 12:00**
site	EFFLUENT
temperature (°C)	15.00
salinity (g/kg)	35.46
average turbidity	0.36
membrane	HAWG047S6
MFI (s/l^2)	2.87E+01
	3.02E+01
	3.53E+01
	3.14E+01
viscosity (@20°C) (kg/m.s)	1.10E-03
viscosity (kg/m.s)	1.22E-03
dP˚ (Pa)	2.07E+05
dP (Pa)	2.07E+05
A˚ (m^2)	1.38E-03
A (m^2)	1.38E-03
MFI˚ (s/l^2)	**3.49E+01**

VISCOSITY	
T (°C)	0-180
S (g/kg)	0-150
S(i)	0.03546
a1	1.57E-01
a2	6.50E+01
a3	-9.13E+01
a4	4.28E-05
mu_w(i)	1.14E-03
a5	1.54E+00
a6	2.00E-02
a7	-9.52E-05
a8	7.97E+00
a9	-7.56E-02
a10	4.72E-04
A	1.82E+00
B	6.95E+00
mu(i)	1.22E-03

	RUN [1]		**RUN [2]**		**RUN [3]**	
time (s)	**volume (l)**	**t/V (s/l)**	**volume (l)**	**t/V (s/l)**	**volume (l)**	**t/V (s/l)**
0	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
10	*0.22*	*45.45*	*0.23*	*43.48*	*0.20*	*50.00*
20	*0.36*	*55.56*	*0.38*	*52.63*	*0.35*	*57.14*
30	*0.50*	*60.00*	*0.53*	*56.60*	*0.48*	*62.50*
40	*0.62*	*64.52*	*0.65*	*61.54*	*0.60*	*66.67*
50	*0.75*	*66.67*	*0.77*	*64.94*	*0.72*	*69.44*
60	*0.86*	*69.77*	*0.88*	*68.18*	*0.83*	*72.29*
70	*0.97*	*72.16*	*0.99*	*70.71*	*0.94*	*74.47*
80		*#DIV/0!*	*1.10*	*72.73*		*#DIV/0!*
90	*1.17*	*76.92*	*1.20*	*75.00*	*1.14*	*78.95*
100	*1.26*	*79.37*	*1.30*	*76.92*	*1.23*	*81.30*
110	*1.35*	*81.48*	*1.39*	*79.14*	*1.31*	*83.97*
120	*1.42*	*84.51*	*1.47*	*81.63*	*1.39*	*86.33*
130	*1.50*	*86.67*	*1.55*	*83.87*	*1.47*	*88.44*
140	*1.56*	*89.74*	*1.62*	*86.42*	*1.55*	*90.32*
150	*1.63*	*92.02*	*1.70*	*88.24*	*1.61*	*93.17*
160	*1.70*	*94.12*	*1.77*	*90.40*	*1.69*	*94.67*
170	*1.76*	*96.59*	*1.84*	*92.39*	*1.75*	*97.14*
180	*1.82*	*98.90*	*1.90*	*94.74*	*1.82*	*98.90*
190	*1.88*	*101.06*	*1.97*	*96.45*	*1.88*	*101.06*
200	*1.94*	*103.09*		*#DIV/0!*	*1.94*	*103.09*
210	*1.99*	*105.53*	*2.10*	*100.00*	*2.00*	*105.00*
220		*#DIV/0!*	*2.16*	*101.85*	*2.06*	*106.80*
230	*2.12*	*108.49*	*2.22*	*103.60*	*2.13*	*107.98*
240	*2.17*	*110.60*	*2.27*	*105.73*	*2.18*	*110.09*
250	*2.21*	*113.12*	*2.32*	*107.76*	*2.23*	*112.11*
260	*2.26*	*115.04*	*2.38*	*109.24*	*2.28*	*114.04*
270	*2.30*	*117.39*	*2.43*	*111.11*	*2.33*	*115.88*
280	*2.35*	*119.15*	*2.48*	*112.90*	*2.38*	*117.65*
290	*2.39*	*121.34*	*2.53*	*114.62*	*2.43*	*119.34*
300	*2.43*	*123.46*	*2.57*	*116.73*	*2.47*	*121.46*

D. EQUIPMENT SPECIFICATIONS

D.1 HANNA HI98703 PORTABLE TURBIDITY METER

The turbidity of the water was measured with the HANNA HI98703 Portable Turbidity Meter. Table D.1.1 and D.1.2 contains the general and turbidity specifications for this instrument.

Table D.1.1 *– General specifications: HANNA HI98703 portable turbidity meter*

General Specifications	
Light Source	Tungsten filament lamp
Lamp life	Greater than 100,000 readings
LOG Memory	200 records
Serial Interface	USB or RS 232
Environment	Up to 50°C (122°F); max 95% RH non-condensing
Power Supply	(4) 1.5V AA alkaline batteries or AC adapter; Auto-off after 15 minutes of non-use
Dimensions / Weight	224 x 87 x 77 mm (8.8 x 3.4 x 3.0”) / 512 g (18 oz.)

Table D.1.2 *– Turbidity specifications: HANNA HI98703 portable turbidity meter*

Turbidity	
Range	0.00 to 9.99; 10.0 to 99.9 and 100 to 1000 NTU
Range Selection	Automatic
Resolution	0.01 NTU from 0.00 to 9.99 NTU; 0.1 NTU from 10.0 to 99.9 NTU; 1 NTU from 100 to 1000 NTU
Accuracy	±2% of reading plus 0.02 NTU
Repeatability	±1% of reading or 0.02 NTU, whichever is greater
Stray Light	< 0.02 NTU
Typical EMC Deviation	±0.05 NTU
Light Detector	Silicon Photocell
Method	Ratio Nephelometric Method (90°), ratio of scattered and transmitted light; Adaptation of the USEPA Method 180.1 and Standard Method 2130 B.
Measuring mode	Normal, Average, Continuous
Turbidity Standards	<0.1, 15, 100 and 750 NTU
Calibration	Two, three or four-point calibration

D.2 YSI PRO PLUS PORTABLE MULTI-PARAMETER METER

The temperature, conductivity, TDS, salinity, dissolved oxygen and oxidation reduction potential (ORP) of the water is measured using the YSI Pro Plus Portable Multi-parameter Meter. Table E2.1 and E2.2 contains the specifications for this instrument.

Table D.2.1 *– System specifications: YSI Pro Plus portable multi-parameter meter*

System Specifications (Cable and Sensors)	Sensor Type	Range	Accuracy	Resolution	Units	Calibration
Dissolved Oxygen(%) (temp comp range to 5 - 45°C)	Polarographic or Galvanic	0 to 500%	0 to 200% (± 2% of reading or 2% air saturation, whichever is greater) 200% – 500% (± 6% of reading)	1% or 0.1% air saturation (user selectable)	%	1 or 2-points with zero
Dissolved Oxygen(mg/L) (temp comp range to 5 - 45°C)	Polarographic or Galvanic	0 to 50 mg/L	0 to 20 mg/L (±2% of the reading or 0.2 mg/L,whichever is greater) 20 to 50mg/L (±6% of the reading)	0.1 or 0.01 mg/L (user selectable); 0.1% air saturation	mg/L, ppm	1 or 2-points with zero
Temperature (Field rugged cables)		-5 to 70°C	±0.2°C (±0.3°C cables over 45-meters)	0.1°C	°C, °F, K	
Temperature (Lab-grade)*		0 to 40°C	±0.35°C	0.1°C	°C, °F, K	
Conductivity**	Four electrode cell	0 to 200 mS/cm (auto range)	±0.5% of reading or 0.001mS/cm, whichever is greater (4-m cable) ±1% of reading or0.001 mS/cm, whichever is greater (20-m cable)	0.001 mS/cm to 0.1 mS/cm (range dependent)	µS, mS	1 point
Salinity	Calculated from conductivity and temperature	0 to 70 ppt	±1.0% of reading or 0.1 ppt, whichever is greater	0.01 ppt	ppt, PSU	1 point
pH	Glass Combination	0 to 14 units	±0.2 units	0.01 units	mV, pH units	1, 2, 3, 4, 5, or 6 Electrode point (user selectable); US, NIST or Custom Buffers
ORP	Glass Combination Electrode	-1999 to +1999 mV	±20 mV in redox standards	0.1 mV	mV	1 point
Ammonium*** (ammonia with pH sensor)	Ion Selective Electrode	0 to 200 mg/L-N, 0 to 30°C	±10% of reading or 2 mg/L-N, whichever is greater	0.01 mg/L	mg/L-N, mV	1, 2, or 3 point (user selectable)
Nitrate***	Ion Selective Electrode	0 to 200 mg/L-N, 0 to 30°C	±10% of reading or 2 mg/L-N, whichever is greater	0.01 mg/L	mg/L-N, mV	1, 2, or 3 point (user selectable)
Chloride***	Ion Selective Electrode	0 to 1000 mg/L, 0 to 40°C	±15% of reading or 5 mg/L, whichever is greater	0.01 mg/L	mg/L-Cl-, mV	1, 2, or 3 point (user selectable)
Total Dissolved Solids (TDS)	Calculated from conductivity and temperature	0 to 100 g/L TDS constant range 0.30 to 1.00 (0.64 default)		0.001, 0.01, 0.1g/L	kg/L, g/L	
Barometer	Piezoresistive	375 to 825 mmHg	±1.5 mmHg from 0 to 50°C	0.1 mmHg	mmHg, inHg, mbar, psi, kPa, ATM	1 point

Table D.2.2 *– Instrument Specifications: YSI Pro Plus portable multi-parameter meter*

Instrument Only Specifications (at Ambient Temperature)	Sensor Type	Range	Accuracy	Resolution	Units	Calibration
pH		-2.60 to 16.60	±0.1 mV (0.01 pH units)	0.1 mV (0.01 pH units)		
ORP		-1999 to +1999 mV	±0.5 mV	0.1 mV		
Conductivity		0.0 to 200 mS/cm each range	±0.1% FS ±1 digit for uS/cm to 0.1 mS/cm (range dependent)	0.0001 mS/cm or 0.1		
Dissolved Oxygen		0.00 to 90 mg/L; 0 to 550%	±0.2% FS (550% air saturation) ±1 digit (with 1.25 PE membrane at 10°C)	0.01 mg/L; 0.1% air saturation		
Temperature		-10 to 100.00°C	±0.2% FS ±1 digit	0.1°C	°C, °F, K	

* Lab-grade cables include 605107, -108, -109, 605177, -178, -179

** Derived parameters can include resistivity, salinity, specifi c conductance, and total dissolved solids

*** ISE sensors for freshwater only; 17-meter maximum depth

D.3 INGE P3 DIZZER® UF ELEMENT WITH MULTIBORE® MEMBRANE

Technical Specification

inge
heart of pure water
Now part of BASF

2.5" / 4" dizzer® Modules

Ultrafiltration elements and pressure housings

- easy installation and handling
- excellent quality of filtrate
- reliable rejection of microorganisms and viruses
- ideal pre-treatment to Reverse Osmosis

TECHNICAL SPECIFICATION

dizzer® Ultrafiltration elements with Multibore® membrane

4" UF elements with Multibore® 0.9

Module data			dizzer® P 4040-6.0		dizzer® P 4021-2.5	
Part number			EP-0049		EP-0048	
Membrane area	m²	sq.ft	6.0	65	2.5	27
Length (L)	mm	inch	960 ± 1.5	37.8	475 ± 1.5	18.7
Outer diameter module (D)	mm	inch	100	3.94	100	3.94
Inner diameter filtrate connection (d1)	mm	inch	28.4	1.12	28.4	1.12
Weight * (wet)	kg	lbs.	4.5	10	2.3	5

4" UF elements with Multibore® 1.5

Module data			dizzer® P 4040-4.0		dizzer® P 4021-1.8	
Part number			EP-0051		EP-0050	
Membrane area	m²	sq.ft	4.0	43	1.8	19.4
Length (L)	mm	inch	960 ± 1.5	37.8	475 ± 1.5	18.7
Outer diameter module (D)	mm	inch	100	3.94	100	3.94
Inner diameter filtrate connection (d1)	mm	inch	28.4	1.12	28.4	1.12
Weight * (wet)	kg	lbs.	4.5	10	2.3	5

2.5" UF elements with Multibore® 0.9

Module data			dizzer® P 2521-1.0		dizzer® P 2514-0.5	
Part number			EP-0047		EP-0046	
Membrane area	m²	sq.ft	1.0	11	0.5	5.4
Length (L)	mm	inch	475 ± 1.5	18.7	300 ± 1.5	11.8
Outer diameter module (D)	mm	inch	61	2.4	61	2.4
Inner diameter filtrate connection (d1)	mm	inch	17	0.67	17	0.67
Weight * (wet)	kg	lbs.	0.7	1.6	0.4	0.9

Technical information

Material				
Housing			PVC-U, white	
Filtrate tube			PVC-U, white	
Filtrate connectors			PVC-U, white	
Operation parameters				
Maximum transmembrane pressure **	bar	psi	3	43.5
Temperature range **	°C	°F	0 - 40	32 - 104

* shipping weight

** To avoid mechanical damage, do not subject the membrane module or element to sudden temperature changes (> 1°C/1 min) or water hammer.

Modules for smal scale applications (e.g. Point-of-Use, Point-of-Entry)

Module name example:

dizzer® P 4040-6.0

- Active membrane area (m²)
- Element length (inch)
- Element outer diameter (inch)
- P series

Pressure housings for dizzer® Ultrafiltration elements

Pressure housings for 4" UF elements

Module data			PV 4040		PV 4021	
Part number			KT-0134		KT-0133	
Length (A)	mm	inch	1130	44.5	648	25.5
Distance connections (B)	mm	inch	1019	40.12	536	21.12
Outer diameter end cap (C)	mm	inch	159	6.25	159	6.25
Outer diameter shell (D)	mm	inch	114	4.5	114	4.5
Threaded connections (E)		inch	3/4" FNPT		3/4" FNPT	

Pressure housings for 2.5" UF elements

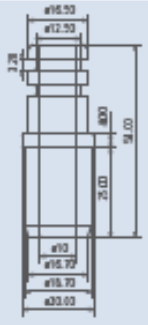
Module data			PV 2521		PV 2514	
Part number			KT-0132		KT-0131	
Length (A)	mm	inch	603	23.75	425	16.75
Distance connections (B)	mm	inch	527	20.75	349	13.75
Outer diameter end cap (C)	mm	inch	95	3.75	95	3.75
Outer diameter shell (D)	mm	inch	73	2.88	73	2.88
Threaded connections (E)		inch	3/8" FNPT		3/8" FNPT	

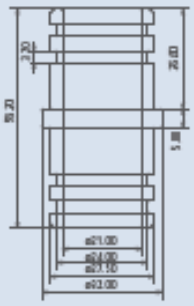
Technical information

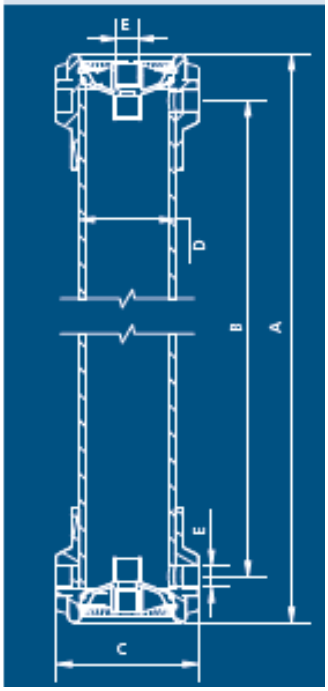
Material			
Housing		PVC-U, white	
Housing end cap		Noryl GTX	
Operation parameters			
Maximum system pressure	bar	psi	10	145
Temperature range	°C	°F	0 - 40	32 - 104

Filtrate connectors for 2.5" and 4" UF elements

2.5" element filtrate connector kit	FC 25	4" element filtrate connector kit	FC 40
Part number	EP-0052	Part number	EP-0053







TECHNICAL SPECIFICATION

Innovative Ultrafiltration with Multibore® membranes

Multibore® membrane 0.9

Membrane data				
Capillaries per fibre			7	
Inner diameter	mm		0.9	
Outer diamter	mm		4.0	
Pore size	µm		approx. 0.02	
Burst pressure	bar	psi	>10	>150
Material			PESM	

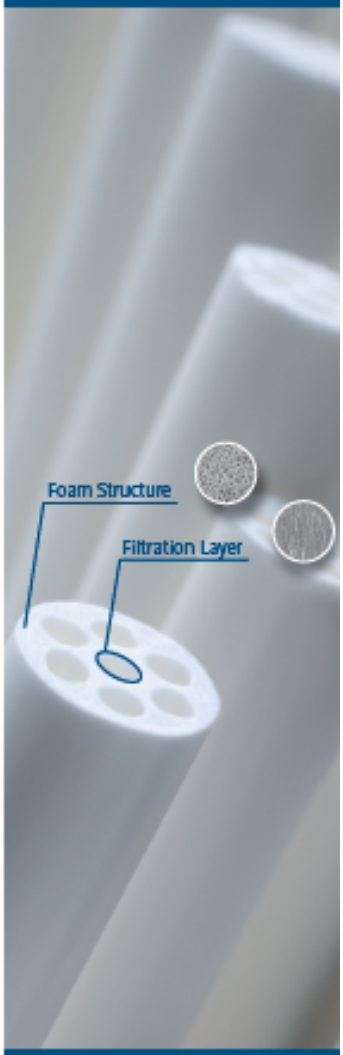
Multibore® membrane 1.5

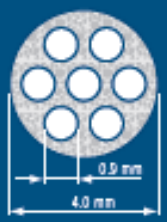
Membrane data				
Capillaries per fibre			7	
Inner diameter	mm		1.5	
Outer diamter	mm		6.0	
Pore size	µm		approx. 0.02	
Burst pressure	bar	psi	>10	>150
Material			PESM	

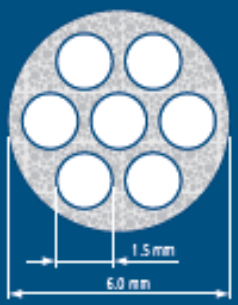
Technical information

Cleaning/disinfection chemicals	Multibore® membrane 0.9 and 1.5	
Free chlorine	ppm ppm x h	max. 200 max. 200.000
H_2O_2 (Hydrogenperoxide)	ppm	max. 500
Caustic Soda pH		max. 13
Acid pH		min. 1

Subject to technical modifications and errors. Modules are to be operated in accordance with the "Installation, Operation and Maintenance Guidelines inge dizzer P Modules" and „Operation and Maintenance Manual PV Series Membrane Housings". Customised configurations are available on request. Please contact the inge GmbH team if you require any further information.







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D.4 DOW FILMTEC SW30-2540 MEMBRANE

FILMTEC™ Membranes
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Product Information

FILMTEC™ SW30-2540 Membranes

Features

Improved FILMTEC™ seawater reverse osmosis elements offer the highest productivity while maintaining excellent salt rejection.

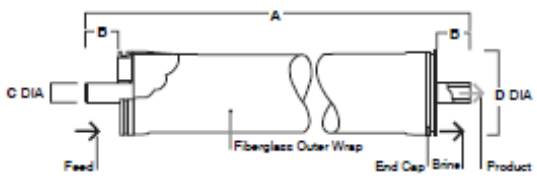
- FILMTEC SW30 membrane elements have the highest flow rates available to meet the water demands of both sea-based and land-based desalinators.
- FILMTEC SW30 elements may also be operated at lower pressure to reduce pump size, cost and operating expenses.
- Improved FILMTEC seawater membrane combined with automated, precision element fabrication result in the most consistent product performance available.

Product Specifications

Product	Part Number	Active Area ft² (m²)	Applied Pressure psig (bar)	Permeate Flow Rate gpd (m³/d)	Stabilized Salt Rejection (%)
SW30-2514	80733	6.5 (0.6)	800 (55)	150 (0.6)	99.4
SW30-2521	80734	13 (1.2)	800 (55)	300 (1.1)	99.4
SW30-2540	80737	29 (2.8)	800 (55)	700 (2.6)	99.4
SW30-4021	80740	33 (3.1)	800 (55)	800 (3.0)	99.4
SW30-4040	80741	80 (7.4)	800 (55)	1,950 (7.4)	99.4

1. Permeate flow and salt rejection based on the following test conditions: 32,000 ppm NaCl, pressure specified above, 77°F (25°C) and the following recovery rates; SW30-2514 – 2%, SW30-2521 & SW30-4021 – 4%, SW30-2540 & SW30-4040 – 8%.
2. Permeate flows for individual elements may vary +/-20%.
3. For the purpose of improvement, specifications may be updated periodically.

Figure 1



Product	Maximum Feed Flow Rate gpm (m³/h)	Dimensions – Inches (mm) A	B	C	D
SW30-2514	6 (1.4)	14.0 (356)	1.19 (30.2)	0.75 (19)	2.4 (61)
SW30-2521	6 (1.4)	21.0 (533)	1.19 (30.2)	0.75 (19)	2.4 (61)
SW30-2540	6 (1.4)	40.0 (1,016)	1.19 (30.2)	0.75 (19)	2.4 (61)
SW30-4021	16 (3.6)	21.0 (533)	1.05 (26.7)	0.75 (19)	3.9 (99)
SW30-4040	16 (3.6)	40.0 (1,016)	1.05 (26.7)	0.75 (19)	3.9 (99)

1. Refer to FilmTec Design Guidelines for multiple-element systems.
2. SW30-2514, SW30-2521 and SW30-2540 elements fit nominal 2.5-inch I.D. pressure vessels. SW30-4021 and SW30-4040 elements fit nominal 4-inch I.D. pressure vessel.

1 inch = 25.4 mm

Form No. 609-00377-0406

Operating Limits

• Membrane Type	Polyamide Thin-Film Composite
• Maximum Operating Temperature	113°F (45°C)
• Maximum Operating Pressure	1,000 psi (69 bar)
• Maximum Pressure Drop	15 psig (1.0 bar)
• pH Range, Continuous Operation[a]	2 - 11
• pH Range, Short-Term Cleaning[b]	1 - 13
• Maximum Feed Silt Density Index	SDI 5
• Free Chlorine Tolerance[c]	<0.1 ppm

[a] Maximum temperature for continuous operation above pH 10 is 95°F (35°C).
[b] Refer to Cleaning Guidelines in specification sheet 609-23010.
[c] Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty, FilmTec recommends removing residual free chlorine by pretreatment prior to membrane exposure. Please refer to technical bulletin 609-22010 for more information.

Important Information

Proper start-up of reverse osmosis water treatment systems is essential to prepare the membranes for operating service and to prevent membrane damage due to overfeeding or hydraulic shock. Following the proper start-up sequence also helps ensure that system operating parameters conform to design specifications so that system water quality and productivity goals can be achieved.

Before initiating system start-up procedures, membrane pretreatment, loading of the membrane elements, instrument calibration and other system checks should be completed.

Please refer to the application information literature entitled "Start-Up Sequence" (Form No. 609-02077) for more information.

Operation Guidelines

Avoid any abrupt pressure or cross-flow variations on the spiral elements during start-up, shutdown, cleaning or other sequences to prevent possible membrane damage. During start-up, a gradual change from a standstill to operating state is recommended as follows:

- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.
- Permeate obtained from first hour of operation should be discarded.

General Information

- Keep elements moist at all times after initial wetting.
- If operating limits and guidelines given in this bulletin are not strictly followed, the limited warranty will be null and void.
- To prevent biological growth during prolonged system shutdowns, it is recommended that membrane elements be immersed in a preservative solution.
- The customer is fully responsible for the effects of incompatible chemicals and lubricants on elements.
- Maximum pressure drop across an entire pressure vessel (housing) is 50 psi (3.4 bar).
- Avoid static permeate-side backpressure at all times.

FILMTEC™ Membranes
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E. CHEMICALS

Chemicals used during the study are as follows:

1. Citric acid monohydrate
2. 2,2-Dibromo-3-nitrilopropionamide (DBNPA)
3. Ethylenedinitrilotetraacetic acid disodium salt dihydrate (EDTA)
4. Flocon 260
5. Hydrex 4101
6. Hydrochloric acid
7. Iron(III)chloride
8. Sodium metabisulfite (SMBS)
9. Sodium hydrosulfite (Sodium Dithionite)
10. Sodium hydroxide
11. Sodium hypochlorite
12. Sodium tripolyphosphate (STPP)